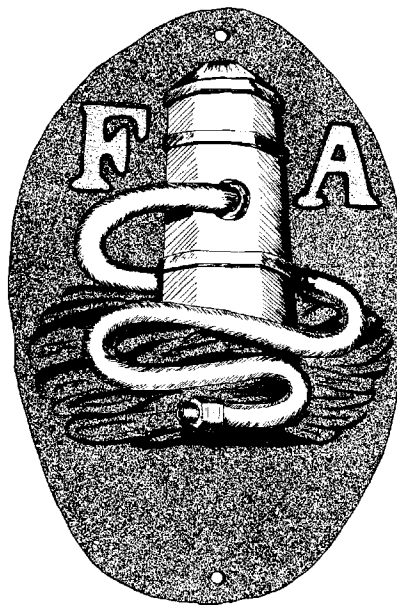


# FIRE PROTECTION SERVICE MANAGEMENT

## FINAL REPORT



By

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"The views expressed herein are those of the researchers and should not be ascribed as views of the National Science Foundation."

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## ABSTRACT

This report presents the results of evaluations of research in the field of urban fire service management. Broadly speaking, the purpose of the report is to provide fire service managers, researchers, and research funders with a readily accessible and usable evaluation of research and related publications relevant to fire service management.

In conducting the study, some 500 references related to fire service management were located and copies of approximately 350, including 65 which were classed as policy-related fire service management research, were obtained. The research reports were subjected to an evaluation by technical experts and comment by a panel of fire service professionals.

Chapters of the report deal with broad, policy-related subject areas with subsections devoted to specific issues within the area. The subsection discussions represent a synthesis of the results of a careful evaluation of policy-related fire management research with information from related nonresearch papers. Thus, the result is more comprehensive than an evaluation of research alone. The report also contains an abstract and internal validity evaluation of each policy-related fire service research report, comments by fire service professionals on policy utility of research subjects, a list of agencies which have funded fire service management research, and a list of organizations which have conducted fire service management research.

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## FOREWORD

This evaluation of policy-related research on Fire Protection Service Management is one of 19 in a series of projects on the Evaluation of Policy-Related Research in the Field of Municipal Systems, Operation, and Services, funded by the Division of Social Systems and Human Resources in the Research Applied to National Needs (RANN) Program of the National Science Foundation.

A large body of research on municipal systems, operations, and services has been created over the last quarter century. However, its usefulness to decision makers has been limited because it has not been evaluated comprehensively with respect to technical quality, usefulness to policy makers, and potential for codification and wider diffusion. In addition, this research has been hard to locate and not easily accessible. Therefore, systematic and rigorous evaluations of this research are required to provide syntheses of evaluated information for use by public agencies at all levels of government and to aid in the planning and definition of research programs.

Recognizing these needs, the Division of Social Systems and Human Resources issued a Program Solicitation in January 1973 for proposals to evaluate policy-related research in 17 categories in the field of municipal systems, operations, and services. This competition resulted in 19 awards in June 1973.

Each of the projects was to (1) Evaluate the internal validity of each study by determining whether the research used appropriate methods and data to deal with the questions asked; (2) Evaluate the external validity of the research by determining whether the results were credible in the light of other valid policy-related research; (3) Evaluate the policy utility of specific studies or sets of studies bearing on given policy instruments; (4) Provide decision makers, including research funders, with an assessed research base for alternative policy actions, in a format readily interpretable and useable by decision makers.



Each report was to include an analysis of the validity and utility of research in the field selected, a synthesis of the evidence, and a discussion of what, if any, additional research is required.

The following is a list of the awards showing the research area evaluated, the organization to which the award was made, and the principal investigator.

- (1) Fire Protection - Georgia Institute of Technology, School of Industrial and Systems Engineering, Atlanta, Georgia, 30332; D. E. Fyffe.
- (2) Fire Protection - New York Rand Institute, 545 Madison Ave., New York, New York, 10022; Arthur J. Swersey.
- (3) Emergency Medical Services - University of Tennessee, Bureau of Public Administration, Knoxville, Tennessee, 37916; Hyrum Plaas.
- (4) Municipal Housing Services - Cogen Holt and Associates, 956 Chapel St., New Haven, Connecticut, 06510; Harry Wexler.
- (5) Formalized Pre-Trial Diversion Programs in Municipal and Metropolitan Courts - American Bar Assoc., 1705 DeSales St., N.W., Washington, D.C., 20036; Roberta-Rovner-Pieczenik.
- (6) Parks and Recreation - National Recreation and Park Assoc., 1601 North Kent St., Arlington, Va., 22209; The Urban Inst., 2100 M St., N.W. Washington, D.C., 20037; Peter J. Verhoven.
- (7) Police Protection - Mathematica, Inc., 4905 Del Ray Ave., Bethesda, Md. 20014; Saul I. Gass.
- (8) Solid Waste Management - Massachusetts Institute of Technology, Dept. of Civil Engineering, Cambridge, Mass., 02139; David Marks.
- (9) Citizen Participation Strategies - The Rand Corp., 2100 M St., N. W. Washington, D.C., 20037; Robert Yin.
- (10) Citizen Participation: Municipal Sub-systems - The Univ. of Michigan, Program in Health Planning, Ann Arbor, Michigan, 48104; Joseph L. Falkson.
- (11) Economic Development - Ernst & Ernst, 1225 Connecticut Ave., N.W. Washington, D. C., 20036; Lawrence H. Revzan.
- (12) Goal of Economic Development - University of Texas-Austin, Center for Economic Development, Dept. of Economics, Austin, Texas, 78712; Niles M. Hansen.
- (13) Franchising and Regulation - University of South Dakota, Dept. of Economics, Vermillion, South Dakota, 57069; C. A. Kent.

- (14) Municipal Information Systems - University of California, Public Policy Research Organization, Irvine, California, 92664; Kenneth L. Kraemer.
- (15) Municipal Growth Guidance Systems - University of Minnesota, School of Public Affairs, Minneapolis, Minnesota, 55455; Michael E. Gleeson.
- (16) Land Use Controls - University of North Carolina, Chapel Hill, Center for Urban and Regional Studies, Chapel Hill, North Carolina, 27514; Edward M. Bergman.
- (17) Land Use Controls - The Potomac Inst., Inc., 1501 Eighteenth St., N.W., Washington, D.C., 20036; Herbert M. Franklin.
- (18) Municipal Management Methods and Budgetary Processes - The Urban Inst., 2100 M St., N.W., Washington, D.C., 20037; Wayne A. Kimmel.
- (19) Personnel Systems - Georgetown University, Public Services Laboratory, Washington, D.C., 20037; Selma Mushkin.

A complementary series of awards were made by the Division of Social Systems and Human Resources to evaluate the policy-related research in the field of Human Resources. For the convenience of the reader, a listing of these awards appears below:

- (1) An Evaluation of Policy Related Research on New Expanded Roles of Health Workers - Yale University, School of Medicine, New Haven, Connecticut, 06520; Eva Cohen.
- (2) An Evaluation of Policy Related Research on the Effectiveness of Alternative Allocation of Health Care Manpower - Interstudy, 123 Grant St., Minneapolis, Minnesota, 55403; Aaron Lowin.
- (3) An Evaluation of Policy Related Research on Effects of Health Care Regulation - Policy Center, Inc., Suite 500, 789 Sherman, Denver, Colo., 80203; Patrick O'Donoghue.
- (4) An Evaluation of Policy Related Research on Trade-Offs Between Preventive and Primary Health Care - Boston University Medical Center, Boston Univ. School of Medicine, Boston, Massachusetts, 02215; Paul Gertman.
- (5) An Evaluation of Policy Related Research on Effectiveness of Alternative Programs for the Handicapped - Rutgers University, 165 College Ave., New Brunswick, New Jersey, 08901; Monroe Berkowitz.
- (6) An Evaluation of Policy Related Research on Effects of Alternative Health Care Reimbursement Systems - University of Southern California, Dept. of Economics, Los Angeles, Calif., 90007; Donald E. Yett.

- (7) An Evaluation of Policy Related Research on Alternative Public and Private Programs for Mid-Life Redirection of Careers - Rand Corporation, 1700 Main Street, Santa Monica, California, 90406; Anthony H. Pascal.
- (8) An Evaluation of Policy Related Research on Relations Between Industrial Organization, Job Satisfaction, and Productivity: Brandeis University Florence G. Heller Graduate School for Advanced Studies in Social Welfare, Waltham, Massachusetts, 02154; Michael J. Brower.
- (9) An Evaluation of Policy Related Research on Relations Between Industrial Organization, Job Satisfaction, and Productivity - New York University, Dept. of Psychology, New York, New York, 10003; Raymond A. Katzell.
- (10) An Evaluation of Policy Related Research on Productivity, Industrial Organization, and Job Satisfaction - Case Western Reserve University, School of Management, Cleveland, Ohio, 44106; Suresh Srivastva.
- (11) An Evaluation of Policy Related Research on Effectiveness of Alternative Methods to Reduce Occupational Illness and Accidents - Westinghouse Behavioral Safety Center, Box 948, American City Building, Columbia, Md., 21044; C. Michael Pfeifer.
- (12) An Evaluation of Policy Related Research on the Impact of Unionization on Public Institutions - Contract Research Corporation, 25 Flanders Road, Belmont, Massachusetts; Ralph Jones.
- (13) An Evaluation of Policy Related Research on Projection of Manpower Requirements - Ohio State University, Center for Human Resource Research, Columbus, Ohio, 43210; S. C. Kelley.
- (14) An Evaluation of Policy Related Research on Effectiveness of Alternative Pre-Trial Intervention Programs - ABT Assoc., Inc., 55 Wheeler St., Cambridge, Massachusetts, 02138; Joan Mullen.
- (15) An Evaluation of Policy Related Research on the Effectiveness for Pre-Trial Release Programs - National Center for State Courts, 1660 Lincoln Street, Denver, Colorado, 80203; Barry Mahoney.
- (16) An Evaluation of Policy Related Research on Effectiveness of Volunteer Programs in the Area of Courts and Corrections - University of Illinois Dept. of Political Science, Chicago Circle, Box 4348, Chicago, Illinois, 60680; Thomas J. Cook.
- (17) An Evaluation of Policy Related Research on Effectiveness of Juvenile Delinquency Prevention Program - George Peabody College for Teachers, Dept. of Psychology, Nashville, Tennessee, 37203; Michael C. Dixon.

- (18) An Evaluation of Policy Related Research on Exercise of Discretion by Law Enforcement Officials - College of William and Mary, Metropolitan Building, 147 Brandy St., Norfolk, Va., 23510; W. Anthony Fitch.
- (19) An Evaluation of Policy Related Research on Exercise of Police Discretion - National Council on Crime and Delinquency Research Center, 609 2nd St., Davis, California, 95616; M. G. Neithercutt.
- (20) An Evaluation of Policy Related Research on Post Secondary Education for the Disadvantaged - Mercy College of Detroit, Dept. of Sociology, Detroit, Michigan, 48219; Mary Janet Mulka.

Copies of the above cited research evaluation reports for both Municipal Systems and Human Resources may be obtained directly from the principal investigator or from the National Technical Information Service (NTIS), U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia, 22151 (Telephone: 703/321-8517).

This research evaluation by David E. Fyffe (PI) of Georgia Institute of Technology on Fire Protection Service Management was prepared with the support of the National Science Foundation. The opinions, findings, conclusions, or recommendations are solely those of the author.

It is a policy of the Division of Social Systems and Human Resources to assess the relevance, utility, and quality of the projects it supports. Should any readers of this report have comments in these or other regards, we would be particularly grateful to receive them as they become essential tools in the planning of future programs.

John Surmeier  
Program Manager  
Division of Social Systems  
and Human Resources

## EXECUTIVE SUMMARY

Over the past two decades, a considerable amount of research has been conducted on problems of fire protection service management. The results of this research are widely scattered and, for the most part, unevaluated and unused. This report is the result of an evaluation of such research and also a comprehensive survey of related nonresearch publications on fire service management.<sup>1</sup>

### OBJECTIVES AND SCOPE

The specific objectives of the study are:

- To provide fire protection service managers with a readily accessible, usable, and critical survey of research results and related publications relevant to their decision-making needs, and
- To provide researchers and research funders with an analysis of the present status and future needs of policy-related research in the area of fire protection service management.

The scope of the subject matter included in the study is restricted to published papers and reports in those areas which are relevant to fire protection service management. Specifically, the literature discussed deals with:

- Operational planning and decision making in fire protection service management. This area includes such matters as cost and effectiveness measurements, organization and personnel administration, management information and control systems, and management of prevention activities.

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1. This project is one of 19 studies to systematically evaluate policy-related research in 17 important areas in the field of municipal systems, operations, and services. The studies were sponsored by the National Science Foundation's Division of Social Systems and Human Resources under the program of Research Applied to National Needs. Funding for this project was provided by Grant GI-39064, July 1973.

- Resource management in fire protection. This area deals with allocation of fire department resources. Examples are location of fire stations, districting for response areas, dispatch policies, and resource allocation among fire department activities.

The study is further restricted to matters pertaining to urban fire department management as opposed to rural, forest, or industrial fire protection, also excluded is research on fires caused by nuclear explosions.

Within this fire service management literature, the part classified as research was restricted to reports

- Containing model development or test of a hypothesis, and
- Directly relating to policy questions in fire protection service management.

The original plan was to restrict the scope of the study to such research. However, as the literature search progressed, it became apparent that a better approach would be to consider all publications concerning fire service management issues. Accordingly, the discussions in this report represent a synthesis and evaluation of available research, design reports, experience reports, and advocacy papers relevant to fire service management. In all, some 500 references were located and copies of approximately 350 were obtained. Special efforts were made to obtain copies of all references which appeared to represent research, and a total of 65 research reports were acquired.

These research reports were systematically evaluated with regard to internal errors, such as improper method or data, by a Technical Review Panel. At the same time, nontechnical assumptions underlying the work were identified and comments were made concerning the apparent need for further research in the subject area. Following this review, a Professionals Panel, consisting of experts and practitioners in the field of fire protection, was convened on the Georgia Tech Campus and asked to comment on the following:

- The importance of the various problems addressed by researchers,
- The validity of assumptions underlying the research, and
- The usefulness of the results from the viewpoint of fire service management.

Drawing on the work of the Technical Review Panel and the Professionals Panel, discussions in this report attempt to present a comparative evaluation of fire service management research and related nonresearch papers pertaining to each policy-related subject area. Critical comments are not intended to reflect on the credentials of the researchers, but rather to assist the users of the work. The authors of this report realize that some research may have been misunderstood and erroneous comments may have been made since there was no opportunity to check with the researchers.

#### SUMMARIES OF MAJOR SUBJECT AREAS

The main report contains six chapters, each devoted to a major subject area related to fire protection service management. Subsections of these chapters are concerned with specific issues. Each subsection presents a comparative discussion of any fire management research and related non-research papers pertaining to the topic area. The final section of each chapter summarizes the status of the work and the perceived research needs.

The following sections correspond to chapters in the report. Each present a brief summary of the research conclusions with suggestions for additional research.

#### Management and Urban Policy Issues in Fire Protection

During the course of discussions by the Professionals Panel, Mr. Joseph Swartz, NFPA, stated that the following four questions were significant to the fire chief:

- How well am I doing given my environment?
- What is it I need to change in my environment?
- How well might I do if I could change my environment?
- What are the resources needed to change it?

Very little useful research exists to help the fire chief find answers to these questions but efforts are beginning to be directed toward the first one. Swartz and an associate have proposed a number of productivity measurements, and a project is now under way at the Urban Institute to develop measurements of effectiveness for fire prevention and fire suppression activities.

In addition to the measurements need, there is another issue which is of great interest to fire service managers. This is the matter of fire

codes. According to comments from the Professionals Panel, badly needed legislation must wait for a major catastrophe before it can be enacted. A comprehensive study of fire codes and their effectiveness was suggested.

The only reported research concerned with the relationship of the fire protection service to other local services is a study of police-fire integration. This very thorough investigation of "coalescence" in the U.S., Britain, and Canada offers empirical evidence that such arrangements are unworkable. However, a number of "experience reports" cite successful integration of the two forces. It should be noted that these were written shortly after the organizational change was made and that no public information is available as to whether or not integration was successful over the long run.

Aside from police-fire integration, little thought has been given to consolidation of other urban services into the fire department. A study by the Burbank Fire Department which recommends that the fire department be given responsibility for building inspections, zoning enforcement, and disaster service is the only exception.

The relationship between the fire protection service and the fire insurance industry has always been quite strong. The ISO Grading Schedule has a major influence on the management of most municipal fire departments (except those in Texas). However, there has been no research seriously attempting to evaluate the consequences of that influence.

#### Administration of the Fire Protection Service

Fire service administration has not had the benefit of significant research. Some work has been aimed at discovering basic psychological and background characteristics of individuals who make good fire fighters; however, no test instruments have been developed and the work is academic as far as fire chiefs are concerned. In other areas of personnel administration, only scattered experience reports and advocacy papers are to be found. For the most part, these papers serve mainly to emphasize the need for thorough study. This seems to be particularly true in the areas of training and job evaluation.

Suppression manpower allocation is the administrative area with the greatest policy utility implications -- according to fire service professionals. Since manpower costs account for approximately 95 percent of fire



department operating costs in many cities, it seems that their evaluation is correct. There is clearly a need for research in the area of company manning and manpower scheduling. Some good research has been done on the matter of proportional rotating schedules for policemen which may have some implications for fire-fighter scheduling. However, the scheduling problem for police is distinctly different from that for the fire service and a similar study is needed for scheduling of firemen.

#### Fire Information and Communications Systems

Some of the most exciting innovations in the fire protection service are those involving information and communications systems. For the most part, these improvements are the result of space-age communications and computer technology. Impetus for adaptation of this technology to urban management, including the fire protection service, has been provided by federal agencies, particularly the Department of Housing and Urban Development.

As a result of these efforts, computer-based information and control systems are now operating in Charlotte, Long Beach, Wichita Falls, Los Angeles, and other cities. Each of these provides a case study of great potential value to those fire departments which design and implement such systems in the future. The next logical step in the evolutionary development and use of computer-based information and control systems is the effective use of the capability which these systems provide. The NFPA has already started this activity for cities using the Uniform Fire Incident Reporting System through a series of seminars and workshops devoted to "Fire Department Management Problem Solving Techniques Using UFIRS Data."

In specific area of alarm systems, an effort to make general use of advanced technology has only just begun. For the most part, the present systems represent large investments and major changes would be very costly. There is a clear and unmistakable need for studies to determine the economic feasibility of various types of alarm systems. So far, the missing component for studies is knowledge concerning fire losses which result from delays in fire detection and reporting. Until someone sheds light on this matter progress is likely to be stymied.

The situation regarding control of traffic signals to speed fire apparatus through crowded streets is much the same as that for fire reporting systems. Technology is available and technical feasibility is established. Economic feasibility must await better data concerning the benefits of these systems.

#### Criteria for Suppression Resource Allocation

Fire suppression resource allocation questions at the company level include "Where should suppression companies be positioned?", "How should companies be repositioned during serious emergencies?", and "What companies should be assigned to respond to particular alarms?" Any attempt to answer these questions requires a criterion or objective function in order to quantitatively evaluate alternatives.

The most important such criterion in fire research has been company response time. Among the implications of research to date are the following:

- Response time is a valid surrogate measure of fire loss. Both the size of the fire and the resources required to control it appear to increase with response time.
- Response time can be efficiently and accurately estimated from rectilinear distance, but a nonlinear time-distance relationship is required for short-distance responses.

The most important response time issue which has not been resolved in the research reviewed is the pattern (linear, exponential, etc.) of growth in fire losses with response time. Better understanding of this pattern of growth would indicate whether longer response times should be given special weight in suppression allocation criteria.

Research on demand for fire suppression services is not nearly as advanced as that on response time. The research reviewed has been largely limited to:

- Documentation of significant time-of-delay, day-of-week, and month-of-year variations in alarm rates; and
- Development of heuristic measures of fire seriousness.

In order for truly valid suppression resource allocation procedures to be developed, research apparently needs to be pursued on:

- Forecasting procedures to predict the alarm rate for different areas and times; and
- Objective measures of the seriousness of fire risk in a neighborhood which are relatively independent of the current locations of fire suppression forces.

Other suppression resource allocation criteria which have been proposed in the research reviewed include:

- Rating standards of the Insurance Service Office (ISO),
- Balance of suppression company workloads,
- Response to nonstructure fire alarms, and
- Societal cost.

However, little research was found which investigated either the relation between these measures and the overall objectives of the fire service, or the sensitivity of resource allocation to the measures. It appears (on the basis of the response of the Professionals Panel) that research is particularly needed on the role nonstructure fire alarms should play in resource allocation.

#### Suppression Resource Allocation

Numerous researchers have proposed or tested procedures for investigating positioning, dispatching, and repositioning policies under various assumptions about the fire suppression environment. By far the largest part of this research has been concerned with positioning, i.e., selection of relatively permanent, "home-base" locations for suppression companies. This research has produced:

- A relatively well-validated set of simple mathematical formulas for rough or preliminary positioning, which are derived from the homogeneous demand case where the alarm rate is assumed constant over the entire region being studied, but can be more widely applied
- A collection of more detailed and complex formulations which position companies at sets of fixed positions
- A limited number of probabilistic results which have implications for the performance of positioning plans in environments where the nearest company to an alarm is not always available

Taken together, these results appear to largely exhaust the possible approaches to the positioning problem, but much more experience with the techniques is required to identify their strengths and weaknesses more thoroughly. It would be particularly useful to have further evidence on the degree to which the quality of the resulting positioning plan is improved when the simple formulas available from the homogenous case are replaced by the more complex covering, or fixed location, schemes.

A considerable amount of research also has been performed on rules for for assigning companies to alarms. This research has demonstrated the value of explicit consideration of the probability that a given alarm signals a serious fire, and produced a set of optimal (under appropriate assumptions) decision rules for both the question, "How many of each type of company to dispatch?" and the question, "Which particular units should be assigned to from the desired number of dispatched units?" These decision rules do not always assign the closest available units.

Pending more widespread implementation, it appears that this research on dispatch rules provides fairly satisfactory answers to the above questions. However, it is not clear whether rules other than the commonly used "assign a predetermined number of the nearest units" rule are necessary except in very large cities. When company workloads are low, the more complex decision rules collapse into this simple and widely used policy.

New York City-RAND Institute research has produced a simple and intuitive scheme for computerized repositioning which appears to meet the needs of New York City. However, some modification of the approach probably would be required to fit the environment in other jurisdictions. Moreover, the repositioning problem is probably only complex enough to require more than dispatcher's judgment in large fire jurisdictions.

Finally, a number of computer simulation routines have been developed which permit more "realistic" testing of complete suppression allocation policy alternatives. Where these routines have been employed, they appear to have yielded worthwhile insight. However, many of the details of the simulations have not been thoroughly validated, and it is not clear that a relatively complex and expensive effort to develop a simulation can be justified in other than the very largest fire jurisdictions.

## Fire Prevention

In spite of the fact that many speakers and writers attest to the importance of fire prevention, there has been very little emphasis on improvement of prevention effort. Only two research studies are reported -- a study of arson which was restricted to juvenile arson in the San Diego area, and a study of fire inspection effort allocation which developed a procedure for the determination of inspection districts. The apparent reasons for the lack of research are (1) difficulty of problems, (2) lack of suitable data, and (3) apparent lack of interest on the part of funding agencies.

Problems related to prevention are indeed difficult. Controlled experiments and other efforts to determine the effectiveness of various prevention activities usually require the cooperation of a great many people and may disrupt established, comfortable procedures. Furthermore, it is almost impossible to isolate the effects of the many variables which influence fire incidence.

Inability to obtain data is rapidly being remedied by computer-based information systems for fire protection and by readily available census data. Yet, even now, most researchers who attempt to work on fire protection service problems of any type find that data constitute a problem.

The general need for research in fire prevention is clear, and the specific areas most in need of careful study are the following:

- Effectiveness of various prevention activities in terms of loss reduction as well as cost effectiveness
- Analysis of fire losses and implications for prevention activities
- Public education needs
  - media effectiveness
  - type of education most needed
  - population strata to which education should be directed
- Effectiveness of codes and regulations
- Penalties as a deterrent to carelessly started fires
- Use of hazard analysis as a basis for prevention effort allocation

## CHAPTER 1

### INTRODUCTION

Over the past quarter century a great deal of research relevant to municipal systems, operations, and services has been carried out. However the results of this research are largely unevaluated and unused. Moreover, most of it is difficult to locate and not directly implementable in actual policy decisions.

In an effort to ameliorate some of these difficulties, the National Science Foundation Division of Social Systems and Human Resources, under the program of Research Applied to National Needs, funded 19 studies to systematically evaluate research in 17 important policy areas. The objectives of the evaluations, as stated in the NSF Program Announcement, were:

- To make a significant body of policy-related research on municipal systems more accessible and usable by policymakers; and
- To provide a more vigorous basis for future research projects dealing with policy-related research on municipal systems.

This document is the final report of one of those studies performed by the School of Industrial and Systems Engineering of Georgia Institute of Technology. The report deals with policy-relevant research in fire protection service management.

#### 1.1 OBJECTIVES AND SCOPE

In keeping with the broad objectives stated by NSF, the specific objectives for this study are:

- To provide fire protection service managers with readily accessible, usable, and critical survey of research results and related publications relevant to their decision-making needs.
- To provide researchers and research funders with an analysis of

the present status and future needs of policy-related research in the area of fire protection service management.

These objectives imply a need to more carefully define (1) the scope of subjects to be included (i.e., what subjects are relevant to fire protection service management policy?), and (2) the qualifications for research (i.e., what constitutes policy-relevant research in the area of fire protection service management?).

Publications in the area of fire protection may be divided by subject matter into the following broad classifications:

- (1) Prevention standards. Examples are flammability standards, building codes, fire regulations, and prevention equipment standards.
- (2) Suppression tactics and equipment. Examples are evaluations of the extinguishment effectiveness of various amounts of water as compared to water property damage, analyses of the utility of various types of fire suppression equipment in dealing with particular types of fires, and damage control.
- (3) Fire technology. Examples are fire spread models, combustion and burning characteristics of materials.
- (4) Operational planning and decision making. This area includes operational decisions related to fire protection service management. Examples are cost and effectiveness measurements, organization and personnel administration, management information and control systems, and management of prevention activities.
- (5) Resource management. This area deals with allocation of fire department resources. Examples are location of fire stations, districting into response areas, dispatch policies, and resource allocation among fire department activities.

This study is concerned with only the last two of these categories. Furthermore, the study is restricted to urban fire protection as opposed to industrial, rural or forest fire protection; and special studies dealing with nuclear fire threats are also ruled out. In short, research reports and other fire-related publications included in this study are those which deal with management of urban fire departments.

Having defined the subject scope of the study, it is necessary to distinguish policy-related research reports from other policy-related publications in the area of fire service management. The following criteria were utilized to make this distinction:

- (1) The effort must include model development or testing of a hypothesis. Data collection alone does not qualify as research. A survey of research does not qualify as research.
- (2) The subject must be directly related to a policy question in fire service management.

Criterion (1) rules out a few studies which consist of data compilation and nothing more, as well as some previous surveys of research.

Criterion (2) rules out theoretical research having only indirect relevance to fire service management. These studies, however, may be mentioned in text discussions and included in "Other Related Papers" referenced at the end of the chapters.

At the outset of the study, it was planned to locate and obtain only fire service management research reports. However, almost immediately it became apparent that this restriction would result in omission of a great deal of relevant information having great potential value to both practitioners and researchers. Much practical knowledge and thought-stimulating comment are found in papers which are related to fire service management, but do not qualify as research. These may be classed and described as follows:

- Design reports. A recent body of literature dealing with design of management systems which is essential to an understanding of current practices in fire service management.
- Experience reports. Papers, usually authored by fire service professionals, describing fire department practices and experience. The contents of these papers is "this is how we do it" or "this is what we did and here is what happened."
- Advocatory papers. Publications which describe concepts or subjectively interpret trends and usually advocate change. These papers are often thought-provoking and may suggest needed research.



A few related studies, outside the project scope but having important bearing on topics of interest, are also mentioned and referenced.

The discussions in this report represent a synthesis of the results of a careful evaluation of policy-relevant fire management research with information from various design reports, experience reports, and advocacy papers. Thus the result is more comprehensive than an evaluation of research, and it should provide practitioners, researchers, and research funders with a thorough review and analysis of what has been done, in both research and practice, in each policy-related subject area.

## 1.2 LIMITATIONS

Like any broad research survey, this study was necessarily subject to a number of restrictions and limitations. As previously stated, the study is limited to literature directly related to the fire service management. An effort was made to locate all literature references (from 1955 to the first quarter of 1974) within the defined scope of the study, and approximately 500 apparently relevant references was found. It is quite possible, however, that some relevant references were missed because the title failed to contain key descriptors or because they were not referenced in the established literature and bibliographies. Moreover, no effort was made to pursue non-fire literature, e.g. police management, even though it might be applicable to fire protection. Finally, the survey was limited to research activity documented in written reports. Thus much good "in house" and "ongoing" work likely was missed.

Attempts were made to obtain copies of each of the fire policy papers referenced. However, in some cases this was not possible because authors and/or publication sources could not be located or because copies no longer exist. Special efforts were made to obtain copies of those references which appeared to represent research reports and these efforts were almost completely successful.

The objective of each subsection of this report is to present a comparative discussion of the fire service management research, if any, and related non-research literature which deals with particular policy

questions. Thus, even if the principal focus of a piece of literature was different than the policy question of interest, relevant parts of the work are discussed. An example is the discussion of cost models wherein those developed to facilitate investigations of other questions are discussed and compared with cost models developed as the principal thrust of research projects. Because such elements of research have been removed from their original context, any criticisms should be viewed as warnings to the user of this element of the research rather than criticisms of the author.

The authors and the Technical Review Panel attempted a very thorough review of each document discussed in this report. Undoubtedly some work was misunderstood and erroneous comments may have been made since there was no opportunity to check with the authors. Moreover, some reports contained insufficient data or detail to enable accurate evaluation, and improper inferences may have been drawn from what was present in the document.

In many cases, criticisms or weaknesses identified in the evaluation and text discussion were already recognized by the author—either in the research report or in subsequent work. Thus, the comments in this report are not intended to reflect on the credentials of the researcher but rather serve as "warning signs" to users of the work. Similarly some preliminary reports and working papers which are generally available and referenced in other publications are included in this report. An attempt is made to properly identify such papers so that tentative or preliminary results are recognized. If any work has been included which the authors do not consider to have been published, we apologize.

### 1.3 APPROACH

The NSF Program Announcement 73-4, in addition to stating the program objectives, also specified that the results of each study were to include the following:

- Evaluation of the internal validity of each research study.  
(Internal validity is determined by whether the research contains internal errors arising from improper methodology, inadequate

data, invalid reasoning or other inadequacies.)

- Evaluation of external validity of the research.

(External validity is determined by whether the research is credible in the light of other valid policy-related research on the same subject.)

- Evaluation of policy utility of the research.

(Policy utility is determined by whether the research is useful in a practical sense.)

The plan for conducting the evaluation study consisted of five interrelated elements designed to achieve the above specifications:

- A literature search and acquisition of papers.
- Classification of papers as fire service management research or other and a further classification into policy-related subject areas.
- Evaluation of research by a panel of technical experts drawn from the Georgia Tech faculty.
- Input from a panel of fire service professionals concerning the importance of research topics, validity of nontechnical assumptions and practical usefulness of results.
- Preparation of the project report synthesizing evaluations by the technical panel and comments of the professionals panel with other policy-related publications in each subject area.

Each of these elements is described in the sections which follow.

#### 1.3.1 LITERATURE SEARCH

The project began with a comprehensive effort to obtain copies of all published literature in fire service management. Most of the research in the area of fire management is comparatively recent. For this reason, the literature search was restricted to the period from 1955 through the first quarter of 1974. Utilizing the resources of the Georgia Tech Library, NASA Literature Search, and other sources, the search was conducted in three phases. First, index and abstract services in the Georgia Tech Library were searched, and publications were solicited from all organizations known to be conducting research in fire service management. For each reference located, an information sheet was

completed and a preliminary judgement made as to whether the work could be classed as (1) within the scope of the project and (2) policy-related fire service management research. Efforts were made to obtain copies of all publications deemed within the scope of the project, but particular emphasis was placed on obtaining copies of those which were obviously research and those which could conceivably qualify as research. We are indebted to the many authors and publishers who responded promptly to our requests.

As documents were received, the reference lists contained therein were checked against those obtained during the first phase of the search and information sheets were completed for any new references. Following these two phases and the development of a detailed subject classification of the field being surveyed, the search team returned to the library to spot check selected topics for thoroughness of the search. The three-phase procedure disclosed some 500 publications related to fire protection service management and copies of approximately 350 were obtained.

The authors were aided in the literature search and various aspects of report preparation by Graduate Research Assistants, John R. Black, Frederick Clark, Jr., William A. Dunphy, Jr., Daniel Gearing, Bruce Schmeiser, Carl Wilburn, and Carl Wohlers. Their assistance is greatly appreciated.

### 1.3.2 CLASSIFICATION

As the study progressed, it was necessary to classify the fire service management literature in several ways. The initial classification of references was concerned with whether or not the work qualified as research. This decision was first made on the basis of title, author, publisher, and a brief abstract (when available) and later refined when reports were received. The criteria given in Section 1.1 provided the basis for this classification.

Fire service management publications which failed to qualify as research were of the following nature: (1) design reports, (2) experience reports, (3) advocatory papers, and (4) related work outside the project scope. No effort was made to classify papers into these non-research categories. However, they are an important part of this evaluation study.

A policy-oriented subject classification of the fire management literature was finalized after receipt of some 300 papers. This classification provides the organization for the main body of this report. Thus, subject areas and sub-topics in the classification represent a compromise between the need to discuss available papers and the need to comprehensively cover the project scope--even if no research was found. However, we believe they provide a policy-oriented framework for discussion of existing fire service management publications and a means to identify areas where research may be needed.

### 1.3.3 TECHNICAL REVIEW

Reports which were classified as fire service management research were subjected to a systematic evaluation beginning with a technical review by a group of qualified experts drawn from the faculty of the Georgia Institute of Technology. Members of this Technical Review Panel were Dr. C. M. Shetty, Dr. Robert G. Parker, Dr. Stuart J. Deutsch, and Dr. Ronald L. Rardin.

Research reports were first briefly reviewed by the Principal Investigator, Dr. D. E. Fyffe, to determine the approach and methodology employed and they were then submitted to an appropriate member of the Technical Review Panel. This individual studied the report, prepared an abstract, and made an evaluation of internal validity. For the purpose of this evaluation, threats to internal validity included the following:

- Incorrect or inappropriate model formulation to describe the real world situation
- Inaccuracies in mathematical methods and calculations used in the study
- Invalid logic or reasoning used to obtain reported results from the analysis performed
- Inadequate or inappropriate statistical analysis
- Inadequate experimental design used to obtain data or empirical results
- Statements or claims which might be subject to serious misinterpretation

In some cases, the report presented preliminary work and was not offered

as a final result by its author. If a later report was available, both the preliminary and subsequent reports were considered for this review and evaluation. When no subsequent report was available, the evaluation was based on the preliminary report alone. In some instances, the report did not contain sufficient detail to permit a critique.

#### 1.3.4 PROFESSIONAL COMMENTS

A logical source for evaluation of the policy utility of research results is the professional who is knowledgeable about practical aspects of fire protection service management. Even more logical is the consensus judgement of a group of such professionals. Accordingly, a panel of fire service experts and professionals was asked to assist with the project.

Members of this Professionals Panel were:

- Mr. Philip Chovan  
Georgia Fire Academy  
Georgia Institute of Technology
- Mr. Hank Christen, President  
Local 134 - LAFF  
Atlanta
- Mr. J. B. Gossett, Chief  
Fire Prevention Bureau  
Atlanta Fire Department
- Mr. John E. Lee, Chief  
Charlotte Fire Department
- Dr. Ralph Long  
Division of Advanced Technology Applications  
National Science Foundation
- Dr. David Miller  
Assistant Professor  
Virginia Polytechnic Institute
- Mr. P. C. O'Connor, Chief  
Technical Services Division  
Metropolitan Dade County Fire Department
- Mr. Joseph Swartz  
Research Division  
National Fire Protection Association
- Mr. P. O. Williams, Chief  
Atlanta Fire Department

In June 1974, the Professionals Panel met for two and one-half days on the campus of the Georgia Institute of Technology. The objectives of these meetings were to obtain inputs from the panel concerning policy.

utility and transferability of the policy-related research; to obtain comments concerning the importance of various subject areas in fire service management; and to obtain general information concerning current practices and problems in fire service management.

In preparation for the Professionals Panel meeting, it was decided that an attempt to individually evaluate the policy utility of each research effort would likely be ineffective since much of the research is highly technical and would require considerable time to present individually. It was reasoned that factors which could result in low policy utility were:

- Irrelevance of the research question itself
- Inappropriate assumptions underlying the research
- Results applying only to a particular organization or environment
- Lack of internal validity

The last of these had been dealt with by the Technical Review Panel. Accordingly, the agenda for the Professionals Panel meeting was organized around the major subject areas of the literature classification. For each subject area, problems examined by various researchers were listed, assumptions were itemized, and efforts were made to succinctly state the policy-relevant research results.

Meetings of the Professionals Panel were conducted as seminars. Each session was introduced with a brief overview of the subject area and the nature of research and related publications in that area. The Panel members were given the lists of research questions, assumptions, and research results and these were discussed. Panel members then were asked to evaluate, on a grading scale, each item on the lists using the following guide:

- Research questions. "Even if this problem were well solved, would anyone really care?"
- Assumptions. "Is this assumption consistent with your own experience?"
- Research results. "How useful are the research results?"

The results of these evaluations are referred to in appropriate sections of this report and are summarized in Appendix C.1.

A bonus from this approach resulted when Mr. Joseph Swartz summarized the research issues presented to the Professionals Panel and obtained comments from fire service professionals who attended an NFPA Seminar and Workshop on Fire Department Management Problem Techniques Using UFIRS Data which was held in Berkeley, California, in July 1974. These individuals were asked the following questions:

- Do you believe, in general, these are valid problems?
- Does this seem to be a relatively complete list of problems?
- Would answers to these problems help your department significantly reduce fire casualties, losses, or other costs?

The responses are summarized in Appendix C.2.

#### 1.3.5 THE REPORT

The major part of this report consists of Chapters 2 through 7, each of which is devoted to a broad policy area related to fire protection service management. Subsections of these chapters are concerned with specific issues. The objective of each subsection is to present a comparative discussion of any fire service management research and related non-research papers which pertain to a particular topic area. The discussions draw upon the internal validity evaluations made by the Technical Review Panel and also the inputs from the Professionals Panel. Thus they deal with the internal validity, external validity, and policy utility of the literature found in each subject area. Suggestions are also made on topics needing further research.

Throughout the discussions, fire service management research reports are referenced with [A-nn] numbers which refer to the bibliography in Appendix A and the abstracts and evaluations of the papers in Appendix B. Non-research papers are referenced with a [chapter number - nn] number relating to the "Other Related Papers" list at the end of each chapter. The same non-research papers may be discussed, and thus referenced, in several chapters if they contain relevant material on more than one policy-related subject. Thus such papers may appear with different numbers in different chapters, but the research papers have the same number throughout.

The final section of each chapter attempts to summarize the important work which has been done in that broad area and reiterates the perceived research needs.



The following Appendices have been included:

- A. Bibliography of Fire Service Management Research Papers Surveyed
- B. Abstracts and Evaluations of Fire Service Management Research Papers
- C. Results of Policy Utility Questions Put to Fire Service Professionals
  - C.1 Professionals Panel
  - C.2 NFPA Seminar and Workshop Group
- D. Publishers of Fire Service Management Research
- E. List of Agencies Funding Fire Service Management Research
- F. List of Agencies Conducting Fire Service Management
- G. Index by Author
- H. Index by Subject.

It is anticipated that researchers and research funders will find the appendices particularly useful.

Appendix A is a bibliography of the fire service management research reviewed in this report. Appendix B contains detailed information (title, author, publication source, purpose, summary, abstract) for each such report.<sup>1</sup> The comments of the Technical Review Panel concerning threats to internal validity are provided together with references to sections in the text containing comments on external validity and policy utility. These references permit the reader to locate all text discussion of that research.

Appendix C contains summaries of the responses of the Professionals Panel together with the response of the NFPA Seminar and Workshop group. These comments from fire service professionals should provide guidance in the selection of meaningful and useful topics for further research.

Appendix D lists the publication sources for both research and related reports. Any publication which had published two or more of the reports disclosed by the literature search is listed here. Appendices E and F list agencies which have funded research in the past and agencies which are known to have conducted fire systems research.

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1. In cases where a researcher has published two or more papers on the same research, these papers are included in one discussion.

## CHAPTER 2

### MANAGEMENT AND URBAN POLICY ISSUES IN FIRE PROTECTION

Examination of research papers and other publications related to management of fire protection service discloses several questions and issues of interest to fire chiefs, urban planners, policy makers, and budget officers. Foremost among these is the question, "How can fire protection service be evaluated?"

It seems to be generally well accepted that fire protection is a "preventive" service. Its objective is to prevent human and economic loss due to fire. Measurement of the success of preventive effort requires assessment of what might have been--a feat which is generally considered impossible without the benefit of divine revelation. Yet, that is what the fire chief needs if he is to determine what combinations of men, equipment, and methods would be most effective in achieving the objectives of his fire department.

Such measures are also needed by urban policy and decision makers. Budget planners, for example, seek to allocate scarce revenues according to perceived needs and expected cost/benefit returns. Commonly, the allocation process requires that management of each urban service prepare a budget proposal which specifies needed expenditures for continuation of service at the current level and requests additional appropriations for increases in service level or quality. Comparative evaluation of proposals is difficult, to say the least. All too often, allocation decisions must be made without adequate information concerning cost/benefit tradeoffs. Such questions as "What is an additional fire company worth" and "Will an addition of two fire inspectors benefit the city more than two policemen?" are not easily answered. Because of this, budget decisions are likely to be made on the basis of political exigencies, public pressure [often from vocal minorities], and what little

factual information that is obtainable.

In addition to the subjects related to budget decisions, managers in the fire protection service and urban managers are concerned with the relation of the fire protection service to other local services such as water and police. It appears that research in this area is lacking, but publications written by professionals in fire protection give some insight into these relationships. In particular, the relationship between the fire department and other local services such as water and police are discussed.

## 2.1 PRODUCTIVITY MEASURES IN FIRE PROTECTION

During the course of discussions by the Professionals Panel, Mr. Joseph Swartz, NFPA, stated that the following four questions were significant to the fire chief:

- How well am I doing given my environment?
- What is it I need to change in my environment?
- How well might I do if I could change my environment?
- What are the resources needed to change it?

Very little useful research exists to help the fire chief find answers to these questions, but efforts are beginning to be directed toward the first one.

In the industrial sector, productivity is commonly measured as "output" per unit of "input." For example, a frequently used productivity measure in the steel industry is "tons of steel per hour of direct labor." In this case, both the output, tons of steel, and the input, labor hours, are well defined and easily measured. Life is not so simple, however, for the fire protection service. Input is generally available in terms of total expenditures, but output is difficult to describe in a specific term which permits measurement.<sup>1</sup>

The difficulty in measuring the productivity of the fire protection service is aggravated by the interactions with other agencies and

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1. The matter of fire protection service outputs will be discussed in detail in Subsection 2.1.1.

consumers of fire protection service. Almost every conceivable output of prevention and suppression effort is affected by factors which are external to the fire department. Preventive effort in the form of public education is shared with schools, federal agencies, and others. The success of suppression efforts is affected by the adequacy of water systems, traffic control, building codes, flammability standards, and the prevention and suppression systems of consumers.

Schaenman and Swartz [2-45] have dealt with the matter of productivity measures for the fire protection service. In a very comprehensive and thoughtful way, they suggest productivity measurements which utilize the following fourteen output factors and three input factors:

#### OUTPUT INDICATORS/SERVICE EFFECTIVENESS

##### --Fire prevention

- (1) Reported fire incident rates
- (2) Number of unreported fires per 1000 population

##### --Fire suppression

- (3) Dollar property loss per building fire
- (4) Spread of damage after arrival
- (5) Response time to fire call
- (6) Insurance rating of fire department, alarm system, fire protection
- (7) Fire-related deaths
- (8) Fire-related injuries
- (9) Property loss per \$1000 property protected

##### --Workload

- (10) Service calls answered
- (11) Service calls per fire company
- (12) Fire prevention inspections made
- (13) Population protected per year
- (14) Property protected per year

#### INPUT MEASURES

- (1) Fire department expenditures
- (2) Paid full-time protection personnel (man-hours)
- (3) Volunteer and part-time personnel (man-hours)

In addition, Schaenman and Swartz have identified a number of "conditioning factors" which are useful in interpreting the output measurements. These are factors which bear upon the success of prevention and suppression efforts but which are external to and, for the most part, uncontrollable by the fire protection service except through influence of legislation and education over the long run. The conditioning factors should be viewed in conjunction with productivity measurements and may help to explain changes in various output measurements. They are as follows:

#### CONDITIONING FACTORS--COMMUNITY CHARACTERISTICS

- (1) Climate and weather
- (2) Area
- (3) Population and population density
- (4) Land use (amount and types of industry, amount of open space)
- (5) Structural conditions
- (6) Road and traffic conditions
- (7) Socioeconomic and demographic characteristics
- (8) Civil disturbances
- (9) Private fire protection measures

Schaenman and Swartz discuss the use of a number of productivity measurements based upon the foregoing output and input factors which are shown in Table 2-1. Illustrative cases for a number of the suggested measurements are presented and analyzed in their report.

The work by Schaenman and Swartz clearly recognizes the multi-dimensional nature of fire protection and acknowledges the inherent difficulties in direct measurements of productivity. The output indicators which they suggest, however, reflect the effectiveness of fire prevention and suppression efforts. They are not intended to be used as a single, one-time measurement, but should be plotted over time to reveal trends and help to indicate the consequences of planned change. Used in this way, the different measures undoubtedly will assist fire chiefs in the management of fire services.

The shortcomings of the measures are clear. First, they may be affected by many factors outside the control of the fire services and

TABLE 2-1. ILLUSTRATIVE PRODUCTIVITY MEASUREMENTS OR PLOTS

Measurement <sup>2</sup>	Type		
1. Population (or property) protected per fire employee man-year or for dollar of fire department expenditures. (The inverses, e.g., dollars or firemen per 1000 population are also useful.)	Overall Workload	per	Overall Input
2. Insurance rating vs. total fire department expenditures per person or expenditures per \$1000 property.	Proxy for Overall Effectiveness	vs.	Overall Input
3. Fire incident rate (per 1000 population) vs. fire prevention expenditures (per 1000 population).	Fire Prevention Effectiveness	vs.	Fire Prevention Input
4. Average dollar loss (or damages spread after fire department arrival at fire) vs. men (or equipment) responding per alarm.	Fire Suppression Effectiveness	vs.	Fire Suppression Unit Input
5. Fires fought per fireman-year (less time spent on fire prevention and non-fire special services).	Fire Suppression Workload	per	Fire Suppression Input
6. Man-hours en route to or at fires per fire fought (viewed with respect to loss and damage spread after arrival per fire).	Fire Suppression Input	per	Fire Suppression Output
7. Fire losses plus, fire department expenditures per \$1000 property; <sup>1</sup> i.e.,  <div style="text-align: center;"> <u>Total Fire Losses and Total Fire Expenditures</u>  Value of Property Served </div>	Total Direct Fire Costs	per	Unit of Workload
<p>1. This measurement is not as easily classified as the others. Note that it imputes an equal weighting to a dollar of loss and a dollar of fire expenditures. A similar measure, using other weightings based on local values, can be constructed, e.g., considering a dollar of prevention to be equivalent to a half dollar of loss--that is, one would be willing to spend more than one dollar to prevent dollars direct property loss.</p> <p>2. Note that most cannot be stated as a single ratio. Each should be viewed over time, and in light of the quality of service.</p>			

(Source: Schaenman and Swartz [2-45])

therefore may be misleading. Dollar property losses per building fire, for example, depend on the fire involvement at the time the alarm is received, the value of the building, the nature and value of contents, whether or not the building is sprinklered, and unavoidable delays in responding to the alarm. Second, many are "negative" measurements in the sense that they emphasize losses rather than positive accomplishments of the fire service (e.g., fire-related deaths as opposed to lives saved).

Pinnell-Anderson-Wilshire Associates,[A-64], in their project for the city of Wichita Falls, Texas, propose a numerical rating which reflects the fire protection capabilities of the fire protection service in a given geographical region. When this rating is used in conjunction with a proposed "fire hazard rating" for the region, the two ratings identify areas of high hazard and low protection and provide administrators with a factual basis for management decisions.

The fire protection rating is obtained by assigning a numerical evaluation to each of the following factors:

- Fire prevention ability
- Fire detection ability
- Fire response ability
- Fire control ability

Each of these factors is further broken into subfactors. Evaluation criteria are presented for rating each subfactor as "good", "fair", or "poor." A proposed fire protection rating form is shown in Figure 2-1. The factors and subfactors do not receive equal weighting. A "good" inspection program, for example, receives 10 points, while a "good" rating for detection is worth only 5 points in the overall numerical rating. The authors make no claim for the relative weightings of the factors. They apparently represent value judgments by experienced fire protection professionals. Neither do the authors explain the choice of factors and subfactors which were selected for the ratings. The proposed fire protection rating scheme results in an overall evaluation of the level-quality of fire protection which is available to a given fire zone.

FIRE PROTECTION RATING FORM			
Zone Number _____; Fire Station No. _____; Date _____; Rated By _____			
I T E M	NUMBER RATING	I T E M	NUMBER RATING
<b>I. FIRE PREVENTION (25)</b> <b>A. Inspection Program</b> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>10</span> <span>5</span> <span>0</span> </div> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>Good</span> <span>Fair</span> <span>Poor</span> </div>			
<b>B. Building Codes</b> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>8</span> <span>4</span> <span>0</span> </div> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>Good</span> <span>Fair</span> <span>Poor</span> </div>			
<b>C. Flammable Materials</b> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>4</span> <span>2</span> <span>0</span> </div> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>Good</span> <span>Fair</span> <span>Poor</span> </div>			
<b>D. Special Hazards</b> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>3</span> <span>2</span> <span>0</span> </div> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>Good</span> <span>Fair</span> <span>Poor</span> </div>			
Sub-Total			
<b>II. FIRE DETECTION (10)</b> <b>A. Detection Systems</b> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>5</span> <span>3</span> <span>0</span> </div> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>Good</span> <span>Fair</span> <span>Poor</span> </div>			
<b>B. Alarm Reporting</b> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>5</span> <span>3</span> <span>0</span> </div> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>Good</span> <span>Fair</span> <span>Poor</span> </div>			
Sub-Total			
<b>III. FIRE RESPONSE (20)</b> <b>A. Response Time</b> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>10</span> <span>5</span> <span>0</span> </div> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>Good</span> <span>Fair</span> <span>Poor</span> </div>			
<b>B. Availability of Equipment and Manpower</b> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>10</span> <span>5</span> <span>0</span> </div> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>Good</span> <span>Fair</span> <span>Poor</span> </div>			
Sub-Total			
COMMENTS: _____ _____ _____ _____		<b>IV. FIRE CONTROL (45)</b> <b>A. Density of Development</b> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>6</span> <span>3</span> <span>0</span> </div> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>Good</span> <span>Fair</span> <span>Poor</span> </div>	
		<b>B. Building Structure Type</b> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>4</span> <span>2</span> <span>0</span> </div> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>Good</span> <span>Fair</span> <span>Poor</span> </div>	
		<b>C. Building Roof Type</b> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>4</span> <span>2</span> <span>0</span> </div> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>Good</span> <span>Fair</span> <span>Poor</span> </div>	
		<b>D. Accessibility</b> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>4</span> <span>2</span> <span>0</span> </div> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>Good</span> <span>Fair</span> <span>Poor</span> </div>	
		<b>E. Explosive or Flammable Mat'l.</b> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>3</span> <span>2</span> <span>0</span> </div> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>Good</span> <span>Fair</span> <span>Poor</span> </div>	
		<b>F. Hydrant Spacing</b> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>5</span> <span>3</span> <span>0</span> </div> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>Good</span> <span>Fair</span> <span>Poor</span> </div>	
		<b>G. Water Flow</b> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>7</span> <span>4</span> <span>0</span> </div> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>Good</span> <span>Fair</span> <span>Poor</span> </div>	
		<b>H. Water Supply</b> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>5</span> <span>3</span> <span>0</span> </div> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>Good</span> <span>Fair</span> <span>Poor</span> </div>	
		<b>I. Sprinkler Systems</b> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>7</span> <span>4</span> <span>0</span> </div> <div style="display: flex; justify-content: space-between; width: 100%;"> <span>Good</span> <span>Fair</span> <span>Poor</span> </div>	
Sub-Total			
TOTAL			
FIRE PROTECTION RATING SUMMARY			
Item		Maximum	Rating
Fire Prevention		25	
Fire Detection		10	
Fire Response		20	
Fire Control		45	
TOTAL		100	

FIGURE 2-1. FIRE PROTECTION RATING FORM

(Source: Pinnell-Anderson-Wilshire [A-64])



While such an evaluation may be useful for an analysis of apparent fire protection needs, it is distinctly different from productivity measurements. First, the evaluations do not deal with ratios of output/input as are required by productivity measurements. Rather, they are based on ratings of factors which are deemed relevant to suppression capability. Such factors need not pertain to the fire department itself. Fire control ability (45 points), for example, depends on such factors as density of development, building structure type, roof type, water flow, etc., none of which is under the management of the fire service. Second, the rating obtained is for a given point in time and is an aggregate measure. Its usefulness is in detecting low protection capability, particularly in zones having high hazard ratings. The authors do not suggest that it be plotted over time. Third, the rating does not measure the fire service itself, since 65 of the possible 100 points are not, as a general practice, under the control of the fire service.

The work by Schaenman and Swartz appears to be the only attempt to deal directly and exclusively with the problem of developing productivity measures for the use of managers of fire protection services. However, the matter of determination of fire service outputs and inputs has been studied by several researchers with the objective of improving fire service decision making. In the following two sections of this report, various research and other publications related to these subjects are examined.

#### 2.1.1 FIRE PROTECTION SERVICE OUTPUTS

As discussed earlier, measurement of the fire protection service output presents serious difficulties. The principal responsibilities of a fire department are fire prevention and fire suppression. However, most urban fire departments provide other emergency services, such as non-fire emergency rescue, ambulance service, disaster assistance, crowd control, and animal rescue. For the most part, researchers have chosen to restrict their work to output measures for fire prevention and suppression efforts. Considering only these two principle functions, the "output" of a fire department can be defined as whatever is produced from the resources committed to these functions--just as the output of a steel plant is whatever is produced.

from the inputs of labor, capital, and materials committed to the plant. It follows, then, that the output of the fire service is the bundle of activities which constitute fire prevention and suppression efforts. The important question is, "How can we measure both the quantity and quality of these activities in ways which will be useful to the urban and fire service managers?"

The literature dealing with this subject offers no definitive answer. Several researchers and other writers have proposed a number of quantity and quality measurements, usually in conjunction with other matters related to fire protection service. The list of output measurements proposed by Schaenman and Swartz in their work on the productivity measurement [2-45] [discussed in Section 2.1] are the most extensive. The first nine of them are measures of quality, while the remaining five are measures of quantity. Hitzhusen [A-19], in his work on the development of a cost-output model for fire protection, discussed the conceptual problems in defining the unit of output of the fire protection service. He concludes that output quantity can be considered to be either the number of people protected or the total value of property protected. Further, he states that output quality has to do with how well people and property are protected and suggests the use of "total number of deficiency points assessed" in the ISO grading as a measure of quality.<sup>1</sup>

Pickett's work [A-44] in the optimal quantity of fire department services also involves an effort to define the output of a fire

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1. The Insurance Service Office (ISO) is a trade group for the insurance industry which conducts evaluations of fire defenses and physical conditions in accordance with a "Standard Grading Schedule." Until the last few years, these evaluations were made by the American Insurance Association (AIA). Most published literature refers to the "AIA Grading Schedule." In this report, we shall interpret these as ISO Grading Schedule. For more on the Grading Schedule, see Section 2.5.

department. Output, he states, is "that bundle of services produced when the fire department performs its functional duties." The single measure which he proposes for these multiple outputs is obtained from the ISO rating. Specifically, he suggests an index number obtained from a reversal of the classification number (e.g., classification 1 results in an output index of 10). He then proceeds to the realization that the insurance classification number changes little, if at all, for most cities and that the proposed index number is useless for the cost function which develops. As a consequence, he proposes a proxy for output which is "total fire department expenditures." This measure is inconsistent with that proposed by other researchers since it actually is an input rather than output.

Ahlbrandt [A-1] utilized the following output measures in his cost model:

- Measure of output level
  1. Population
  2. Area
  3. Assessed value
- Measures of output quality
  4. Response time (proxy measurement is number of stations)
  5. Number of men available to fight a fire
  6. Level of training of manpower
  7. Water pressure available at the site
  8. Index based on the fire insurance classification

The last, he states, is "to capture the dimensions of the quality differences between fire departments." The proposed quality measures are all clearly related to effectiveness in fire suppression. However, they appear to have been selected because of relative ease in obtaining data rather than their accuracy for measuring output quality. Measure 7, water pressure, certainly affects the ability to get water on the fire; therefore, it seems safe to assume that it affects property loss. However, water flow also is affected by size of the water main and it is not considered. Laiming [2-27], in his paper concerning modern fire protection needs, mentions the problem of evaluating the efficiency of fire protection forces and suggests "fire losses per dollar of total

property values threatened" as a desirable measure. Perhaps the most used measure of fire department output quality is "response time." This measure is used frequently by researchers and is highly regarded by professionals in the fire protection service.<sup>1</sup>

Pollak [A-46] discusses measures of fire protection output quantity and quality. He rejects most of those listed above on the basis that either they do not pertain to output as it is provided by the producer without interaction with the consumer or that they are related to input rather than output. "Losses" or "losses averted," for example, are strongly affected by the consumer; and "response time" is clearly related to input. Pollak seeks a measure of physical fire protection output which is independent of consumer characteristics. He reasons that, to the consuming public, service capability is the important factor in fire protection, and that it is the maintenance of service capability which imposes costs. Therefore, he proposes that "suppression capability" be used synonymously with output quality and that it be measured by the percentage of total value remaining after fire department response to fires in a structure selected as standard. This measure is unaffected by level of fire incidence or structural characteristics of properties. It seems, however, to be related to input in much the same way as response time, which Pollak rejects.

It is important to note that output measures were proposed for a variety of uses. Schaenman and Swartz were interested in measures of productivity for use by fire service managers. Hitzhusen, Pickett, and Ahlbrandt proposed output measures for use in regression models for estimating costs. Laiming proposed a measure to reflect the economic evaluation of output quality. It is not surprising, therefore, that there is not unanimous agreement on output measures. A summary is shown in Table 2.2.

There has been no attempt to objectively evaluate the set of proposed output measures. In fact, it appears that no criteria exist for

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1. For detailed discussions of response time as a criterion for fire suppression resource allocation, see Chapter 5.

TABLE 2-2. SUMMARY OF OUTPUT MEASURES

OUTPUT QUALITY MEASURES	Schaenman & Swartz	Pickett	Ahlbrandt	Hitzhusen	Laiming	Rider et al.	Pollak
1. Reported fire incidence rates	x						
2. Number of unreported fires per 1000 population	x						
3. Dollar property loss per building fire	x						
4. Percentage of fires with spread damage after arrival of first fire unit on the scene limited to "X" or fewer damage steps	x						
5. Response time	x		x			x	
6. Insurance rating of fire department, alarm system, and fire prevention	x						
7. Fire-related deaths	x						
8. Fire-related injuries	x						
9. Property loss per 1000 properties protected	x						
10. Total grading schedule rating		x		x			
11. Number of men available to fight a fire			x				
12. Level of training of manpower			x				
13. Water pressure available at the site			x				
14. Index based on fire insurance classification			x				
15. Fire losses related to property values threatened					x		
16. Total fire department expenditures		x					
17. Suppression capability							x
OUTPUT QUANTITY MEASURES							
1. Number and rate of service calls answered by type of call	x						
2. Average number of calls responded to per fire company	x						
3. Number and rate of fire prevention inspections	x						
4. Population protected per year	x		x	x			
5. Value of property protected per year	x		x	x			
6. Area protected			x				

such an evaluation. Other than the arguments of Pollak, very little has been written concerning the characteristics which a good measure should possess.

### 2.1.2 ECONOMIC WORTH OF FIRE PROTECTION

In the preceding section, attempts to define and measure the output of fire service were reported and discussed. In this section, attention is focused on the economic value of fire protection. How much is fire protection service worth to the community? How can this value be measured? The Professionals Panel unanimously agreed that a good answer to these questions would be very useful.

Economic worth of fire protection can be looked upon as a comprehensive measure of fire service output. It implies that there are benefits which result to the public from fire protection and requires that these benefits be valued in dollars and cents. Some benefits of fire protection are the following:

- (1) Prevention of property losses (the economic difference between realized losses and what could have happened with no fire protection service).
- (2) Prevention of human losses (the savings in loss of life and suffering which are attributable to fire protection).
- (3) Reduction in fire insurance premiums.
- (4) Savings in medical costs.
- (5) Reduction in loss of productive capacity and productivity.

It is difficult to quantify these benefits in terms of dollars. However, a few researchers have presented various proposals for measuring benefits (always in the context of research dealing with other questions), and other writers have commented on benefits measurement.

Shoup [2-48] discussed fire damage briefly with the following statement:

The output of the fire department can be measured only in increments, not in totals or averages, because the service is a preventive one, and there is no way of knowing (and no need to know) how much fire damage would occur if the government offered no fire protection service at all. What can be observed is the reduction in rate of fire damage when an increment of fire protection is added. A clue to the amount of such reduction is the decrease in fire insurance premiums that

occurs when an increment of fire protection service is added.

Pickett [A-44] suggested precisely this incremental reduction in fire insurance costs in his approach to determining an "optimal" level of fire protection service.

Laiming [2-27], writing in 1965, urged reasonable appraisals by experienced fire officers of "estimated property values involved in fires" in order to obtain an economic evaluation of suppression effort. He stated that German fire officers, after the experience of observing and evaluating the spread of unattended fires during World War II, concluded that fire suppression efforts held fire losses to about 5 percent of what would have occurred without fire protection service.

Malko [A-36] approached the matter of benefit evaluation by hypothetical examination of the consequences of no public fire protection service. He concluded that under this situation the alternatives are (1) adequate private fire protection service and (2) inadequate or no private fire protection with attendant higher fire insurance costs. He assumed the latter and used insurance premium reduction that is caused by the existence of public fire protection services as a measure of benefits to households and businesses. It should be noted that Malko was not concerned with an absolute measure of benefits but rather the proportional distribution of fire benefits.

Gordon, Drozda, and Stacy [A-15] considered reductions in insurance premiums, benefits from reduced property losses, and benefits from saving of human life in their working paper on cost-effectiveness. They reject the use of insurance premium reductions and concentrate on the latter two items. Since these are impossible to quantify, they turn to factors which correlate with these benefits. They state that most evidence indicates that reduced response time is likely to reduce losses (no evidence is cited) and suggest empirical studies to confirm or disprove the hypothesis. The loss vs. response time relationship established by such studies--if valid--could aid in economic analysis of expenditure decisions. They further state that evidence indicates response is a crucial factor in life loss and suggest studies to explore this relationship.

It appears that there has been little serious effort to determine the economic worth of fire protection service and that researchers who have touched upon the matter have taken the easy way out by accepting reductions in fire insurance costs as the only economic benefit to both households and businesses. This measure is inadequate. Moreover, it reflects an inequitable distribution of benefits between households and businesses. Households, for example, receive little or no insurance benefit from fire protection improvements which raise the ISO classification above a Class 6. Businesses, on the other hand, may receive considerable benefit.

Admittedly, there is no objective way to evaluate losses prevented. From a practical standpoint, it is virtually impossible for the fire officer to accurately estimate the percentage of involvement upon arrival at the fire scene because of smoke. However, attempts at empirical studies are certainly worthwhile and could serve to shed some light where there is now darkness.

## 2.2 COSTS OF FIRE PROTECTION

The report of the National Committee on Fire Prevention and Control [2-61], published in May 1973, lists the following types of costs which are attributable to fires:

- Property loss
- Fire department operation
- Burn injury treatment
- Operating cost of insurance industry
- Productivity loss

and puts the total of these at \$11.4 billion annually with the costs of fire department operations at \$2.5 billion. It is not clear whether such costs as private extinguishment equipment (e.g., sprinkler systems, fire extinguishers, etc.) and fire-related costs incurred by urban services other than the fire department are included. In any case, there is no doubt that the economic losses due to fires are staggering. When 12,000 lives and untold suffering and misery are added to the economic loss, the total is cause for national concern.



Such figures as this estimate of aggregate losses may serve to emphasize the importance of the fire protection service, but they are not very useful in its management. As previously stated, the output of the fire department is preventive service and its objective is to prevent loss due to fire. We now further add that the objective is to do so at lowest cost; or, alternatively, to deliver the greatest quality service (quantity is fixed by area, population, etc.) for the available resources. The central question for the urban manager is, "Will the benefit derived from an incremental expenditure in the fire service be greater than could be obtained from that expenditure elsewhere?" and the central question for the fire service manager is, "How can output quality be improved at least cost?" Thus, the fire service manager must make decisions concerning alternatives for allocation of resources and justifications of need for additional resources. The remainder of this section contains discussions of cost-related work for the purpose of assisting urban and fire service managers in their continuing struggle with these questions.

#### 2.2.1 COSTS AS A BASIS FOR PRODUCTIVITY MEASURES

Schaenman and Swartz list fire protection expenditures as one input measure for the fire protection service. They state that dollar expenditures on fire protection include most (not necessarily all) fire department expenditures plus incremental expenditures by other government services for fire protection, (e.g., added water costs due to fire protection needs). The exclusion of nonfire services (e.g., ambulance services) and separation of prevention and suppression costs permit direct monitoring of such costs for management purposes and also their use as input measures to which various output measures can be related. For example, fire incidence rate (per 1000 population) vs. fire prevention expenditures (per 1000 population) and property protected per fire employee man-year vs. fire department expenditures are proposed measurements for tracking fire department productivity. The Professionals Panel expressed a strong interest in such measurements.

### 2.2.2 COST-BENEFIT ANALYSIS

A fundamental approach to resource allocation decisions is to compare the incremental benefit of various alternatives to the incremental cost of providing the benefit. This approach is called "cost-benefit" or "cost-effectiveness" analysis.<sup>1</sup> It is a useful approach to decision problems involving expenditure of funds if the number of alternatives is limited. Generally speaking, estimated costs can be obtained by straightforward use of available prices. Estimating the value of incremental benefits is often much more difficult because it is not always easy to identify the benefits derived from the incremental inputs; moreover, they are very difficult to quantify.

Although recognized as an important management tool, cost-benefit analysis has not been the subject of directly related research. Pickett [A-44], in his thesis on determination of the optimal quantity of fire department services, proposed a cost-benefit analysis for decisions involving increased service. In his proposal, the costs of each alternative for increasing the insurance classification by one point are estimated and the least cost for achieving the objective is compared with the benefits to the community. The benefits are measured by the reduction in fire insurance costs. The decision maker assumes that the public would be willing to pay the increased fire service costs if the decrease in the price of fire insurance exceeds the added cost. It seems clear that the proposed approach also requires assumptions that total benefits are reflected in insurance rate reductions and that these reductions are distributed to property owners in the same proportion as fire insurance costs. Neither of these assumptions seems consistent with reality.

Gordon, Drozda, and Stacey [A-15], in a working paper prepared for Battelle's Urban Studies Advisory Council, emphasized the difficulties in estimating marginal benefits. Their discussion concentrates on the benefits accruing from changes in insurance premiums, reductions in

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1. For a general discussion of cost-effectiveness analysis related to fire protection service, the reader should see Jarrett's paper [2-21].

property loss, and savings of human life. Unlike Pickett, they reject the use of insurance premium reductions as a factor for resource allocation decisions for the following reasons:

- (1) Gradings are infrequent and subjective, thus making estimation of insurance premium changes almost impossible.
- (2) The Standard Grading Schedule is strongly oriented toward property protection. Resource allocation decisions based upon its use would not reflect considerations for human life and injury.
- (3) Reductions in insurance premiums as a result of moving from one grade to a higher grade accrue to commercial and manufacturing firms more than to homeowners.

Hitzhusen [A-19] attempted to study and compare the cost-benefit relationships of several types of public fire protection improvements in Texas and New York resulting in insurance key rate decreases. The reader who has any doubt about the difficulties in performing such a study should read Hitzhusen's report. His plan was to use insurance premium savings as a measure of benefit accruing from the various improvements and relate these savings to actual costs for improvements. However, obtaining data for costs and benefits proved to be extremely difficult and Hitzhusen was forced to use a number of estimates. He points out, in considerable detail, that difficulties arise from the use of insurance costs as a measure of benefits. The results obtained by Hitzhusen differ according to which estimate of insurance cost savings were used. Although he presents specific results of the analysis and draws some general conclusions, he is forced to qualify each conclusion according to the benefit estimate used. His results, then, provide useful information to the fire service manager only to the extent that (1) insurance premium savings are an adequate measure of total benefits from the improvements, and (2) one of the estimating methods provides an accurate measure of fire insurance premium savings to the community.

The policy utility of the matter of cost-benefit analysis appears to be high. The few research efforts which have been reported appear to serve primarily as testimony to the difficulties of such efforts.

It seems fairly clear, however, that insurance premium reductions are not a good measure of total benefits and that empirical studies to establish better measures are needed. Ideally, the measure should include savings in property loss, life, and injury. There is some evidence to indicate that response time correlates with these losses. However, perhaps it would be interesting to divide the life cycle of a structure fire into the following time segments:

- (1) ignition to detection,
- (2) detection to the time report is received,
- (3) report receipt to departure,
- (4) departure to arrival of first unit, and
- (5) arrival to knock down.

Studies to relate each of these components to loss of property and life for various types of fires would be very useful.

### 2.2.3 COST MODELS

Analysis of the relationships between costs and various factors related to demand, quantity, quality, and environmental conditions is a matter which has received considerable attention. Cost models expressing fire service expenditures and other related costs as a function of various factors which are felt to influence the magnitude of these costs have been proposed and tested by Pollak [A-46], Hitzhusen [A-19], Ahlbrandt [A-1], Pickett [A-44], Hirsch [A-18], Pidot [A-45], and others.

For the most part, cost models have been developed in order to explore issues such as the following: (1) economies of scale in the fire protection service, (2) costs of competitive vs. bureaucratic procedures of fire protection service, and (3) determination of an "optimal" quantity of fire protection. However, the works of Pollak, Hirsch, and Pidot represent attempts to analyze the relationships between expenditures and various factors related to fire protection. In what follows, the cost models proposed by the several researchers will be first presented, discussed, and compared. After this comparison, the issues listed above will be discussed and evaluated.

Ahlbrandt [A-1] chose a log-linear cost model in preference to a quadratic model in order to relate the variables listed in Table 2-3 to costs per capita.<sup>1</sup> Adjusted budgeted operating costs and capital expenditures were included on the cost side. Depreciation, interest on debt, and rent were not included because they were not available for most of the departments studied. Costs related to water were not included since they are not ordinarily part of a fire department's budget.

Ahlbrandt obtained data from 44 fire departments in the state of Washington. These included (1) all-volunteer, (2) combination paid-volunteer, and (3) all-paid forces. This information was used to determine regression coefficients for the cost model also shown in Table 2-3.

The results of Ahlbrandt's empirical study indicate that the fire insurance rating, which reflects quality level, has a strong relationship to costs (particularly in all-paid fire departments) and that increase in the number of people does not require an increase in fire department operations expenditures. Ahlbrandt did not explain why he chose not to consider a linear model, and it is apparent that his selection of independent variables was severely restricted by practical considerations of obtaining data. The coefficient of multiple determination<sup>2</sup> was calculated to be .962 and his equation may be useful in predicting fire department expenditures, but it appears to offer little help in understanding relationships between decision variables and fire protection costs.

Hirsch [A-18] proposed a quadratic cost function which relates per capita fire protection expenditures plus debt service to the seven variables in Table 2-4. Using data for 1952-1956 from 32 St. Louis area

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1. Log-linear equations have terms containing the logarithms of variables and have the form

$$\ln y = a \ln X_1 + b \ln X_2 + c$$

2. The coefficient of multiple determination represents the percentage of variability in the data which is explained in the regression model. A high value does not necessarily mean that the equation will produce good forecasts.

TABLE 2-3. AHLBRANDT COST MODEL

## VARIABLES:

- $y$  = cost per capita in dollars  
 $X_1$  = population from 1970 census in thousands  
 $X_2$  = area in square miles  
 $X_3$  = assessed value in millions of dollars  
 $X_4$  = percentage of housing units lacking all or some plumbing facilities (1970 census data)  
 $X_5$  = adjusted wage index  
 $X_6$  = fire insurance rating index  
 $X_7$  = number of aerial ladder trucks  
 $X_8$  = number of aid cars  
 $X_9$  = number of volunteers  
 $X_{10}$  = number of fire stations (proxy for response time)  
 $X_{11}$  = number of full-time personnel (proxy for level of training and speed of action)

## REGRESSION EQUATION:

$$\begin{aligned}
 \ln(y) = & 4.52 - 21.61 D_2 - .98 \ln(X_1) - .11 \ln(X_2) + .32 D_2 \ln(X_2) + .83 \ln(X_3) \\
 & - .23 D_1 \ln(X_3) - .74 D_2 \ln(X_3) + .14 \ln(X_4) - .45 D_1 \ln(X_5) \\
 & + .59 D_2 \ln(X_5) - .59 \ln(X_6) + .69 D_1 \ln(X_6) + 3.61 D_2 \ln(X_6) \\
 & + .12 \ln(X_8) + .17 \ln(X_9) + .32 \ln(X_{10}) - .31 D_1 \ln(X_{10}) + .24 \ln(X_{11})
 \end{aligned}$$

In this equation,  $D_1$ ,  $D_2$  are dummy variables as follows:

$$D_1 = \begin{cases} 1 & \text{for combination paid-volunteer department} \\ 0 & \text{otherwise} \end{cases} \quad D_2 = \begin{cases} 1 & \text{for all-paid department} \\ 0 & \text{otherwise} \end{cases}$$

These dummy variables permit certain independent variables to have different coefficients for the three types of fire departments.

COEFFICIENT OF MULTIPLE DETERMINATION:  $R^2 = .962$

TABLE 2-4. HIRSCH COST MODEL

VARIABLES:

- $X_1$  = nighttime population
- $X_2$  = area in square miles
- $X_3$  = density of dwelling units per square mile
- $X_4$  = 1950-1955 nighttime population increase
- $X_5$  = combined receipts of wholesale, retail, and service establishments
- $X_6$  = index of scope and quality of fire protection
- $X_7$  = average per capita assessed evaluation of real property

REGRESSION EQUATION:

$$\begin{aligned}
 y = & 0.63 - 0.0000235 X_1 + 0.000\ 000\ 000\ 109 X_2^2 - 0.086 X_2 \\
 & + 0.000\ 00170 X_3 - 0.00206 X_4 - 0.000\ 0108 X_5 + 1.889 X_6 \\
 & + 0.00231 X_7
 \end{aligned}$$

COEFFICIENT OF MULTIPLE DETERMINATION:  $R^2 = 0.82$

fire departments, Hirsch obtained the regression equation also shown in Table 2-4. As with Ahlbrandt's work, quality factors appear to have an overwhelming relationship to costs. (The quality measure Hirsch employs is the index based on insurance premium rates.)

As a part of a much broader study of measures of local government service output, Hitzhusen [A-19] looked at several versions of cost functions for fire protection service. His models include the variables listed in Table 2-5. Using data from a random sample of 140 Texas municipalities, Hitzhusen obtained regression equations for adjusted 1969 fire department operating costs. The first equation expresses fire department operating costs per capita as a function of population, ISO deficiency points, property value per capita, manpower arrangements, firemen's average salary, and ISO deficiency points for climatic conditions. The variables omitted were found not significant.

Hitzhusen is the only researcher to consider costs per unit value of property protected as the dependent variable. The second regression equation in Table 2-5 shows the results. As additional cost components are included in the dependent variable, the cost equations have progressively higher explanatory power. Equation 3, for example, has a coefficient of multiple determination of 0.9262. The implication seems to be that better equations can be found for obtaining cost per unit of property value protected than for costs per capita, and that explanatory power increases as the definition of fire protection costs is made more comprehensive.

In addition to the empirical models for Texas communities, Hitzhusen developed comparable cost/output models for New York. He found that it was necessary to modify the Texas models substantially because of New York's diverse fire protection organizational arrangement and different data availability. Models were developed, however, and regression coefficients were obtained, using data from 32 New York City and village fire departments and 38 fire districts.

Pickett [A-44] developed a cost model for use in estimating total fire department expenditures for several cities in Missouri. The variables considered and their definitions are shown in Table 2-6.



TABLE 2-5. HITZHUSEN COST MODEL

VARIABLES:

- $C_1$  = Adjusted 1969 fire department operating cost
- $C_2$  =  $C_1$  + annual charge for capital
- $C_3$  =  $C_2$  + annual charge for volunteer effort
- $C_4$  =  $C_3$  + annual charge for water supply
- $C_5$  =  $C_4$  + private fire insurance costs estimated from projected premiums
- $C'_5$  =  $C_4$  + private fire insurance costs estimated from key rate and property value data
- $O_1$  = Population protection in 1969 (output quantity)
- $O_2$  = Full value of property protected in 1968 (output quantity)
- $Q$  = Inverse of output quality or total ISO deficiency points assessed against public fire protection (water supply, fire department, fire alarm and fire prevention)
- $X_{1a}$  = Full value of property per capita,  $O_2/O_1$  (for equations  $C_1/O_1$ )
- $X_{1b}$  = Population per \$10,000 full value unit of property  $O_1/O_2$  (for equations  $C_1/O_2$ )
- $X_2$  = Total property taxes collected in 1966-1967 per unit of property value protected
- $X_3$  = Full paid vs. other fire department manpower arrangements (for equations  $C_1/O_1$ ,  $C_1/O_2$ ,  $C_2/O_1$ , and  $C_2/O_2$ )
- $X_4$  = Average monthly salary for firemen or hosemen in 1969
- $X_{5a}$  = Intergovernmental revenue received in 1966-1967 per capita (for equations  $C_1/O_1$ )
- $X_{5b}$  = Intergovernmental revenue received in 1966-1967 per unit of property value protected (for equations  $C_1/O_2$ )
- $X_{6a}$  = Population protected ( $O_1$ ) per square mile (for equations  $C_1/O_1$ )
- $X_{6b}$  = Full value of property protected ( $O_2$ ) per square mile (for equation  $C_1/O_2$ )
- $X_7$  = Total ISO deficiency points assessed for adverse climatic conditions
- $X_8$  = Total ISO deficiency points assessed for unusual occurrences
- $X_9$  = Percent of property protected that is commercial
- $X_{10}$  = Percent of structures built in 1939 or earlier
- $X_{11}$  = Percent of population classified as Negro in 1960

TABLE 2-5. (Continued)

VARIABLES: (Cont'd.)

$X_{12}$  = Percent population of Mexican foreign stock in 1960

$X_{13}$  = Percent population of German foreign stock in 1960

REGRESSION EQUATIONS:

$$1. \quad C_1/O_1 = 6.26 - .1213 (1/O_1) - .197 Q + .0494 X_{1a} + 1.516 X_3 \\ + .0027 X_4 + .0537 X_7$$

$$2. \quad C_1/O_2 = 12.89 + .1654 (1/O_2) + .0113 X_{1b} + .0109 X_4 + .0972 X_7 \\ + .1944 X_{11} + .1305 X_{12}$$

$$3. \quad C_5^1/O_2 = 45.78 + 2.192 (1/O_2) + .0850 X_{1b} + .1263 X_2 + .0269 X_4 \\ + .2611 X_{6b} + .1820 X_9$$

COEFFICIENTS OF MULTIPLE DETERMINATION:

$$1. \quad R^2 = 0.64$$

$$2. \quad R^2 = 0.6495$$

$$3. \quad R^2 = 0.9262$$

TABLE 2-6. PICKETT COST MODEL

VARIABLES:

- y = Total fire department expenditures
- X<sub>1</sub> = Total number of full-time employees in the city
- X<sub>2</sub> = Total general municipal expenditures in thousands of dollars
- X<sub>3</sub> = Total wages and salaries paid by the fire department in thousands of dollars
- X<sub>4</sub> = Total full-time paid employees of the fire department
- X<sub>5</sub> = Duty hours per week of fire department employees
- X<sub>6</sub> = Total city population
- X<sub>7</sub> = Total general revenue of the city in thousands of dollars
- X<sub>8</sub> = Total number of all housing units
- X<sub>9</sub> = Area served in square miles
- X<sub>10</sub> = Total number of occupied housing units
- X<sub>11</sub> = Total sales of retail establishments in millions of dollars
- X<sub>12</sub> = Total sales of wholesale establishments in millions of dollars
- X<sub>13</sub> = Total sales of service establishments in millions of dollars
- X<sub>14</sub> = Value added by manufacture in millions of dollars
- X<sub>15</sub> = Total number of retail establishments
- X<sub>16</sub> = Total number of wholesale establishments
- X<sub>17</sub> = Total number of service establishments
- X<sub>23</sub> = Total number of manufacturing establishments
- X<sub>24</sub> = Sum of X<sub>16</sub> + X<sub>17</sub> + X<sub>18</sub> + X<sub>19</sub>
- X<sub>25</sub> = Sum of X<sub>20</sub> + X<sub>21</sub> + X<sub>22</sub> + X<sub>23</sub>

REGRESSION EQUATION:

For Jefferson City, Missouri

$$y = 156.9 + 6.2 X_4 - .48 X_5 + .01 X_{10}$$

COEFFICIENT OF MULTIPLE DETERMINATION:  $R^2 = 0.976$

Annual data for the years 1950-1965 were obtained from 14 cities in Missouri and, after testing some alternatives, a linear cost model was selected. Regression equations were obtained for each of the 14 cities and cross-sectional equations were obtained for each year. An example is the cost equation for Jefferson City, which is given in Table 2-6. It should be noted that all of the variables considered by Pickett are "quantity" type factors and that they are strongly interrelated. These shortcomings substantially weaken the work.

Pidot [A-45], in a study of the determinants of local government fiscal patterns, examined 30 explanatory variables which are thought to be relevant to fire protection costs. He applied principal components analysis to create a smaller set of uncorrelated measures which explain a maximum amount of the variance from the original variables.

In his analysis of fire protection, Pidot used a total of eight independent variables (six of which are principal components) and determined their relationship to 1962 fire department expenditures per capita in 81 United States metropolitan areas. The independent variables and the regression equation are shown in Table 2-7.

Since "metropolitanism" has such a strong positive relationship to costs per capita, perhaps it deserves further comment. This component reflects high population density and, consequently, slow or negative growth rate, with large suburban populations and a commuting labor force using public transportation. Urban housing tends to be older and renter occupied.

Pidot did not include fire protection-related costs other than fire department expenditures, and the variables from which principal components are derived pertain to output quantity and environmental factors. No quality-related factors were included. This appears to be a serious shortcoming. The use of principal component analysis to reduce multicollinearity results in more reliable individual coefficients. Whether or not this provides more explanatory power is an open question.

Pollak [A-46] presents a very interesting and intuitively appealing deductive analysis of factors affecting fire protection cost. He argues that total fire protection costs are a function of population, area,

TABLE 2-7. PIDOT COST MODEL

VARIABLES:

- y = fire department expenditures per capita
- X<sub>1</sub> = total state aid in 1962
- X<sub>2</sub> = total federal aid in 1962
- C<sub>1</sub> = metropolitanism (exemplified by mature urban complexes such as New York City)
- C<sub>2</sub> = inverse measure of wealth (exemplified by low-income and poor housing)
- C<sub>3</sub> = general inverse index of size
- C<sub>4</sub> = absence of older and low-income people, and presence of a manufacturing base
- C<sub>5</sub> = heavy residential base, presence of manufacturing base as opposed to retailing
- C<sub>6</sub> = crude measure of stagnation

REGRESSION EQUATION:

$$y = 6.209 + .031 X_1 + .114 X_2 + 3.062 C_1 - .566 C_2 + .242 C_3 \\ - .513 C_4 - .135 C_5 - .507 C_6$$

COEFFICIENT OF MULTIPLE DETERMINATION:  $R^2 = 0.663$

and service output level ("suppression capability"). He reasons that population affects demands for service through the increased alarm rate, but that elevated alarm rates are more appropriately the result of social and economic conditions accompanying high population density. Accordingly Pollak suggests "alarms per capita" as an independent variable. He concludes that, for a given service level, costs will vary in proportion with area and population changes, somewhat less than in proportion to an area where population is held constant and much less than in proportions of population changes when the area is constant. Further, he concludes that service level (response time) marginal costs rise as service level is increased.

As a result of deductive analysis, he suggests that the appropriate form of the cost function is

$$\text{Total Cost} = KA^{\alpha} N^{\beta} f\{\hat{d}\}$$

where A denotes area, N denotes population,  $\hat{d}$  denotes service level,  $\alpha$  is close to but less than one, and  $\beta$  is close to but greater than zero.

Pollak maintains that the reported empirical studies suffer from inadequacies which make them virtually useless as a means for testing hypotheses concerning cost factors and their relationship to costs. First, the studies imply that expenditure levels established in the political process can be adequately described by the supply-demand models proposed. Second, they imply (for the most part) expenditures per capita as the dependent variable and do not include service level--or else use an inappropriate measure of service-level--as an independent variable.

There seems to be substantial validity to Pollak's objections. The usual process through which funds are allocated to the fire department is political and, therefore, influenced by factors which no research would or could include in a regression model. With regard to quality-related factors, it is interesting to note that in the two models in which they were included (Hirsch and Ahlbrandt), their coefficients in the regression equation were comparatively large. Yet, these were crude and perhaps inappropriate quality measures. Most

researchers dealt only with factors related to demand, environment, and cost--ignoring quality completely.

In addition to these shortcomings, there are other inadequacies in the empirical cost studies which call for great caution in their interpretation. An examination of independent variables in the models reveals strong intercorrelation.<sup>1</sup> Fire insurance rating, for example, is closely correlated with the number of fire stations. High intercorrelation among the explanatory variables results in lowered reliability for the individual regression coefficients. Therefore, the high values for the coefficient of multiple regression which are often obtained in these studies must be understood to mean that the included variables statistically "explain" much of the observed cost variation. It is risky to ascribe obvious interpretation to the individual coefficients. Moreover, as the work of Pickett demonstrates, empirical studies using data from different cities (but the same variables) often produce markedly different results.

In short, empirical cost analyses appear to contribute very little to an understanding of the relationship between fire protection costs and the factors which seemingly influence these costs. Perhaps it is just as well, then, that fire protection professionals seem to view the matter with considerable disinterest. While the knowledge of how selected variables influence costs has some utility for long-range planning, the nature of public service financing and the urban budget process do not facilitate the use of such information. As stated previously, however, most of the cost models were developed as a means of testing hypotheses concerning other issues. Judgment of them should be based on their suitability for the intended purpose rather than their ability to identify factors which affect costs.

2.2.3.1 ECONOMIES OF SCALE. Several of the preceding cost models have been used to investigate economies of scale for fire protection service.

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1. Explanatory variables are said to be intercorrelated if knowledge concerning one of them also provides information concerning one or more of the remaining variables.

In so doing, it is necessary to make restrictive assumptions concerning the behavior of other variables in the cost model. Ahlbrandt [A-1], for example, assumed that all independent variables which are related to community size increase by the same percentage as population and that all other independent variables remain constant. Under this assumption, he examined the results of increasing population on costs per capita for the volunteer, paid-volunteer, and fully paid fire departments included in his study. The conclusion was that for volunteer and combination paid-volunteer departments there are decreasing returns to scale. For fully paid departments, however, he claimed that fire service expansion occurs at virtually constant cost per capita. Ahlbrandt correctly cautioned that cost models should not be used to infer economies of scale unless the behavior of other independent variables is known. Although not mentioned by Ahlbrandt, it also should be noted that most empirical cost models are developed with short-run data and may be inappropriate models for long-run per capita expenditures.

Hirsch [2-18] examined cost per capita increases as a function of population and concluded that, for the St. Louis area, per capita costs decline slightly as population increases to 110,000 and increase sharply as population expands further. This behavior is seen to be more a result of physical size of service area rather than population per se. His conclusions are consistent with those of Pollak [A-46] in his deductive analysis of fire department costs. Pollak stated, "per capita costs of given protection have been argued to be relatively constant when area and population vary together, to rise precipitously with density declines and to decline precipitously with density increases."

Will [A-62], in his study published in 1965, also examined the question of economies of scale in urban services. His approach is distinctly different from those previously discussed.<sup>1</sup> Using the ISO

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1. Will develops a general method for determining economies of scale associated with urban government services. However, for reasons of practicability in data requirements, he is forced to abandon this "ideal" method and resort to an approximate method for his fire protection service study.



"Standard Schedule," he obtained professional expertise to estimate the required number of "standard units of effort" to achieve the same level of protection service in each of 37 cities ranging in population from 50,000 to one million. He then converted the standard unit of effort to cost per capita. These costs are intended to show the costs of reaching a uniform level of protection in cities of various sizes. Will then related these costs to population by regression analysis and concluded that there are significant economies of scale up to a population of 300,000 and very little from that point on.

Aside from the fact that Will's approach relies heavily on subjective judgment, it is also strongly biased by the economies of scale which are inherent in the ISO Grading Schedule. The question which he actually examined was, "Does it cost more, per capita, to meet uniform ISO Grading Schedule requirements for a small city than it does a large one?" His results indicated that the answer is a qualified "Yes."

Overall, the research which has been reported on economics of scale in fire protection service does not appear to have contributed a great deal. Specific questions concerning the economic desirability of merging fire protection jurisdictions are best answered by specific cost analyses. Examples of experience reports concerning economies obtained by consolidations are Waters [2-56] and Streuli [2-50]. Waters' paper reports on the conditions preceding the consolidation of the city of Jacksonville, Florida, with surrounding Duval County and the actions during the first and second years following consolidation. His report is a testimony to the increased efficiencies resulting from the consolidation. Streuli described the consolidation of the Contra Costa County Fire District, California, in an address delivered to the Seventy-fourth NFPA Annual Meeting held May 18-21, 1970, in Toronto. He describes the benefits obtained by consolidation in terms of financial benefits, service improvements, resource improvements, and others. These reports by those who have experienced successful consolidation of fire departments seem to confirm that economies of scale exist.

2.2.3.2 COSTS OF COMPETITIVE VS. BUREAUCRATIC PRODUCTION OF FIRE PROTECTION SERVICES. Ahlbrandt, using the cost function which he

developed, examined the hypothesis that "the competitive supply of fire service is more efficient than that of a bureaucratic monopoly." His approach was to develop the cost function to estimate the cost of bureaucratic supply for Scottsdale, Arizona. This figure was then compared with the actual costs for the competitive producer supplying Scottsdale. He found that the estimated cost per capita for a bureaucratic producer serving Scottsdale and the actual per capita cost for Scottsdale were \$7.10 and \$3.78, respectively.

This surely seems impressive, but several matters should be examined before the hypothesis is accepted on the basis of this comparison. First, are equivalent services actually delivered? If not, then costs are not comparable. Second, if services are equivalent, what are the cost-reducing innovations of the competitive producer? Are they generally transferrable? If not, then the hypothesis should be restricted to the Scottsdale situation.

As might be expected, the issue of "competitive producer vs. bureaucratic monopoly" was not received with great interest by the Professionals Panel who participated in this evaluation project.

#### 2.2.4 ALLOCATION OF FIRE PROTECTION COSTS TO CONSUMERS

The subject of financing municipal services has been discussed by Vickrey [2-54] and Shoup [2-48], among others. The general question is whether the consuming public should pay for specific municipal services through (1) general tax levies made without regard to benefits received, or (2) specific taxes or fees which distribute costs of the service according to benefits received. Although many papers devoted to the general subject contain sections pertaining to the fire service, the literature search for this evaluation project disclosed only the work of Malko [A-36] devoted to the subject of allocating municipal fire protection expenditures to business and households.

Malko suggested two alternatives for allocating fire protection service costs in relation to benefits. The first proposed alternative distributes fire protection expenditures in proportion to the distribution of the total fire insurance premium reduction that results from the existence of the fire protection service. That is, the reductions

in fire insurance rates that are caused by the existence of the fire protection services are multiplied by value of buildings and contents in order to estimate the total reduction in premiums. Fire protection costs are then allocated to a particular consumer in accordance with his pro rata share of the total premium reduction.

In the second proposed method, actual fire insurance rates are used as a proxy for probabilistic values of using public fire protection service. Total expenditures are allocated to fire or household  $i$  according to the following ratio:

$$R = \frac{(\text{fire insurance rate } i)(\text{value of property of firm or household } i)}{\sum_{i=1}^n (\text{fire insurance rate } i)(\text{value of property of firm or household } i)}$$

Thus, the second method allocates fire protection costs to a specific consumer according to the ratio of his fire insurance costs to the total of fire insurance costs for the city.

Malco attempted to apply both of these allocation methods--the first to Milwaukee and the second to New York City and Washington, D.C. As a result, he concluded that a tax base composed of adjusted real property conforms to the benefits rationale of taxation better than does the tax base consisting of unadjusted real property.

### 2.3 RELATION OF FIRE PROTECTION TO OTHER LOCAL SERVICES

Fire protection is only one of the many public services commonly provided by local governments. Quite obviously, it does not function independently. Only a little effort is required to think of ways through which other agencies affect the activities of the fire protection service. Blum [2-5] describes these dependencies in the following paragraph:

To carry out these activities effectively, the fire service depends heavily upon outside persons and agencies: those who formulate and administer the codes, architects and building contractors, fire insurance companies (whose

rating practices influence private fire protection, such as detectors, sprinklers, or brush clearance that property owners provide); telephone companies, private or auxiliary alarm services, and equipment manufacturers and suppliers. These form important additional parts of the fire protection "system." And when they perform poorly, they impair the fire service's ability to carry out its mission.

The most important dependency relationships, however, are those with the water department and police department. These and other relationships of local service to fire protection will be discussed in the sections which follow.

### 2.3.1 RELATION OF FIRE PROTECTION TO WATER

In most cities, water for fire fighting is supplied by the public water service. The water supply is so vital to fire suppression efforts that it is considered the single most important element in the ISO Grading Schedule. It has a relative value of 39 percent with 1950 points.

Although there has been research on the technical aspects of water in fire suppression which are outside the scope of this study, the literature search failed to disclose any research dealing with studies of the relation of fire protection to the water department. There are, however, a few "experience reports" which may be of interest to fire service professionals and researchers. O'Hara [2-38] describes a program of water system improvements and practices instituted by the town of Arlington, Massachusetts. Rando and Bendix [2-40] describe design standards for the fire protection water system in San Francisco. This system is separate and distinct from the public water utility, operated by the fire department, and "dedicated to the principle that the city will never be destroyed by fire again for lack of water." In addition to these, the Orange-Seminole-Osceola Planning Commission [2-66] examined water supply in its report on fire protection for the East Central Florida Regional Planning Council. Also, Philadelphia experiences in Fire and Water Department Cooperation are described in FIRE ENGINEERING [2-73].

### 2.3.2 RELATIONSHIP OF FIRE PROTECTION TO POLICE

It is not surprising that consideration should be given to combining police and fire protection. Both are emergency services and have minor duties which overlap. Both are needed at the fire scene and both may be needed at the scene of an accident. The public seems to be about as likely to call one as the other in an emergency situation. In some cities, both departments, although distinct and separate, report to a Public Safety Commissioner.

A number of cities have combined fire and police functions to at least some extent. It is not possible to cite all advocacy publications and experience reports dealing with varying degrees of fire-police integration, but the following are noted: Danville, Virginia [2-52]; Winston-Salem, North Carolina [2-17]; Burnsville, Minnesota [2-14]; Fremont, California [2-12]; East Grand Rapids, Michigan [2-77]; San Diego, California [2-4]; Evanston, Illinois [2-23]; Glencoe, Illinois [2-37]; and Sunnyvale, California [2-22]. Advocatory arguments are contained in "Should Police and Fire Departments Be Combined?" which appeared in The American City [2-81] and "Where Police-Fire Integration Works" by G. W. Fairholm [2-16]. The literature search disclosed no experience reports dealing with disadvantages of fire-police integration or reports of abandonments of trial efforts, although it is known that Elgin, Illinois; Scottsville, Kentucky; Ironwood, Michigan; Fremont, California; West Miami, Florida; and Lincoln, Nebraska; among others, have abandoned efforts to combine the two services. Actions which indicate strong dissatisfaction with combined fire-police functions include a Pennsylvania law prohibiting the integration of police and fire departments of third-class cities and a Massachusetts law providing that a fire fighter in cities of over 40,000 population shall not be required to perform the duties of a police officer.

Cunningham [A-12] completed a very comprehensive study of police-fire integration (he prefers the term "coalescence") in 1968. It is a massive work which discusses the arguments for and against coalescence, where it has been tried and where it has failed, and the politics involved. In addition to the discussions of police-fire integration in the United States and Canada, Cunningham traces a 100-year history in

Great Britain through two major wars and ending with prohibition by act of Parliament in 1947. He states that "The British experience is virtually unknown in the United States and nothing is known to have been published on the subject in Great Britain." On the basis of his analysis of both the British experience and United States efforts, he finds that there is no great economy in police-fire integration. Small cities realized some savings, but in cities larger than 100,000 population, coalescence was more costly than separate services. He states, "No city is known to have reduced its total budget for the two services through adoption of coalescence."

In addition, he cites specific examples of poor fire suppression performance of combined services and finds that they have a remarkably lower capability of adaptation to a rapidly changing ecology than separate services. Also, he states that coalescence interrupts the network of mutual assistance between municipalities.

Cunningham's work is so thorough as to leave little more to be done except perhaps an up-date of his analysis.

### 2.3.3 RELATIONSHIP OF FIRE PROTECTION TO OTHER AGENCIES

Schaenman and Swartz [2-45], in their discussion of fire protection productivity measurements, point out that in addition to the police and water departments, there are several other agencies which directly or indirectly affect fire protection. They state the following:

Other government agencies, in addition to the fire department, are relevant to fire protection and affect the principal measures. The local water supply (distribution, pressure, number and type of hydrants) is of course crucial to effective fire suppression activities. The local road network and the ability of police to control traffic and crowds strongly influence a firefighter's ability to get to and work around a fire. The public health service, school system, and other local and state government agencies often share the fire prevention workload. These and other factors, such as building codes, actions of building inspectors and planners, play an important role in fire protection service.

A proposal to consolidate some of the fire service-related activities into the operations of the fire department has been made by Burbank Fire Chief R. V. Christofferson. In a special study of the organization, operations, equipment, and manpower needs of the Burbank Fire

Department [2-63], he recommends that the fire department be given responsibility for the following functions now assigned to other agencies:

- Building Department
- Zoning Enforcement
- Disaster Services

The Burbank report argues that the objectives of the services performed by these departments are consistent with those of the fire department. It is pointed out that well over half the building code is concerned with fire prevention and that many small cities have their building codes administered by the fire department. Furthermore, the knowledge and abilities required of a building inspector are very similar to those required of a fire inspector. The arguments for placing zoning enforcement responsibilities with the fire department state that the objectives of zoning (i.e., control of land use, population density, the location of structures, height and bulk of structures, and open space about structures) are parallel to the objectives of the fire department. Moreover, it is claimed that the activities of zoning inspection are compatible with the usual qualities of fire protection personnel. Arguments which are given in the Burbank report for placing disaster service with the fire department are very convincing. It is pointed out that both the tools and methods of disaster service are the everyday responsibility of the fire department.

The role of the fire department as an "emergency service" seems to be gaining increasing acceptance. Our Professionals Panel felt strongly that the fire department should be viewed in this broader role and that this was a natural evolution of the fire protection service. They pointed out that, in recent years, a number of urban fire departments have initiated emergency medical services complete with modern ambulances and trained paramedic personnel.<sup>1</sup>

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1. The Professionals Panel agreed that the television series, "Emergency," has played an important role in increasing public acceptance of this emergency service.

In addition to the possibilities of consolidating fire protection-related agencies, there is the possibility of closer cooperative effort between such agencies and the fire department. Stone [2-49] reports the experience of Ivey Johnson, Chief Electrical Inspector, Miami, Florida, in joint investigation with fire investigators of fires of possibly electrical origin. His experiences indicate that there is much to be gained by such cooperative effort.

## 2.4 FIRE IN URBAN PLANNING

There is no reported research concerning the fire protection aspects of urban planning. A few non-research papers purport to deal with the subject, but these were found to be reports of efforts to plan for fire protection services using forecasts of urban population growth. Some of these reports and a few advocacy papers provide arguments for "what needs to be done" about including fire protection considerations in the urban planning process.

A report from the East Central Florida Regional Planning Commission specifies the following need for cooperation:

- SCHOOL BOARD--The location of schools should consider distance and time to the nearest fire department. The design of school sites should allow fire and rescue equipment to move freely to possible trouble. Water supply, sprinkler systems, and stand-pipe design location should be coordinated with fire officials while planning new buildings and in reconditioning older ones.
- PLANNING, ZONING, AND BUILDING OFFICIALS--Fire officials should be called upon for their comments when rezoning is considered since fire protection may be seriously affected. Review of preliminary plans by fire officials is urged in cases of apartment complexes, public facilities, high-rise buildings, and shopping centers. Mutual briefings by fire and planning officials can result in better ordinances, better planning, and safer development.
- CITY AND COUNTY ELECTED OFFICIALS--Organized fire protection needs to be established in all urban communities within the



metropolitan area that are not now served. The adoption of new ordinances, such as the requirement for sprinkler alarm systems in high-rise buildings, needs consideration. Establishment of a consolidated fire department within each of the counties, or an intercounty organization, should be considered. More equitable taxation for fire protection throughout the metropolitan area should receive priority.

Maatman [2-30], in a paper prepared in 1962, also advocated that city planners and public officials broaden the scope of their thinking to more adequately consider municipal fire protection needs.

There is little or no evidence that city planners and administrators today are more conscious of these needs than those in the past. Hughes [2-20], in a paper concerning traffic planning and fire service published in 1971, stated the following:

It frustrates me and indeed my colleagues, when one is required to impress professional people holding high administrative positions, with a responsibility for hundreds of thousands of people; that unless they get their priorities right, they will have no children to play in their proposed play areas or people to enjoy the newly planned environment.

## 2.5 INSURANCE EVALUATION OF FIRE PROTECTION

The relationship between the fire insurance industry and the fire protection service has been very close over many years. Indeed, the earliest fire departments in the United States were formed and supported by insurance firms. Most modern municipal fire departments in the United States are now organized and operated according to engineering standards established by the fire insurance industry.

At the beginning of this century, the capital stock fire insurance companies became concerned with the conflagration potential in American cities. The National Board of Fire Underwriters, an association of fire insurance underwriters, began to study this threat in 1904 following the Baltimore conflagration. After an intensive engineering study a "Standard Schedule for Grading Cities and Towns with Reference to Their Fire Defenses and Physical Conditions" was developed and adopted in 1916. Several revisions have been made over the years, with the

latest being in 1974.<sup>1</sup> Also, responsibility for conducting municipal fire protection surveys has been passed to the Engineering and Safety Department of American Insurance Association and more recently the Insurance Services Office. The items considered in the Grading Schedule and the ten city classifications are shown in Table 2-8. With the exception of Texas, most states use the ISO Grading Schedule and these ten classifications with some variations.

TABLE 2-8. FACTORS CONSIDERED IN THE ISO GRADING SCHEDULE

Category	Total Points	%
Water Supply	1950	39
Fire Department	1950	39
Subtotal (Suppression)	3900	78
Fire Service Communication	450	9
Fire Safety Control	650	13
	5000	100

The city classification is the basis for a "key rate" for each individual or class of property in the city. This rate is, of course, affected by any improvement or deterioration in the fire defenses of the city which results in a classification change. Thus the "better" the fire protection, the lower should be the insurance rates. The matter of rate making, however, is not within the defined scope of these evaluations. What is important to these discussions is the impact, favorable or unfavorable, which insurance-based grading of fire defenses has on fire protection.

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1. The Grading Schedule is available from The Insurance Services Office, 160 Water Street, New York, New York 10038.

There is no reported research study which examines the effects of the Grading Schedule on the planning and operation of fire protection service. However, several researchers (in discussions of their research methods or findings) have made critical comments on the subject. Kimball [2-24], however, strongly supports the favorable contributions of the Grading Schedule and states that it has been a major factor in "helping cities in the United States to enjoy a level of fire protection superior to that of cities in any other part of the world." McClellan [2-31] states, "The United States has the worst record on fires of the industrialized, high technology nations of the world. America is the per capita leader in deaths from fires and also holds the international lead in property losses from fires." Regrettably, no facts are cited to support either of these conflicting statements. Laiming [2-27], however, provides data comparing fire protection resources in five of the world's largest cities which is shown in Table 2-9. These figures indicate that the two United States cities, New York and Chicago, provide more resources per capita than any of the foreign cities. It appears that Kimball is referring to resource level, while McClellan is looking at losses. If both Kimball and McClellan are correct, there is much we could learn about fire prevention and suppression from other countries.

The Grading Schedule and its impact on fire protection have been criticized by several writers. The basis for criticism is:

- The grading process is concerned only with quantity--men, machines, trucks, ladders, hoses, water pressure, etc.--and ignores the effectiveness with which they are used, and
- The grading schedule reflects the conflagration risks existent in 1900. Pollak [A-46] claimed that these shortcomings in the grading process contribute to making fire departments "tradition bound and generally closed to innovation and externally suggested change." The statement is clearly an opinion and is not supported in his work.

Arslaner [A-3], in his comparative study of three municipal fire departments, states the following:

TABLE 2.9. COMPARISON OF FIRE SERVICES IN FIVE OF THE  
WORLD'S LARGEST CITIES

	New York	Chicago	Tokyo	London	Paris
Area, square miles	318	199	278	616	187
Population, thousands	7,782	3,550	10,000	8,500	6,000
Paid firemen	13,160	4,700	9,875	6,530	4,400
Fire stations	248	142	238	122	59
Fire companies (4 men or more on duty)	368	214		360	156
Major fire apparatus	568	300	575	370	215
Note: The area and population given are for that portion of each city subject to one fire department. The data for London refer to the Greater London Fire Brigade, which came into being April 1, 1965.					

(Source: Laiming [A-45])

The consequences of municipal grading or classification systems for municipal fire protection administration are highly important. The concept of grading substantially influences the program priorities allocated. The concern of municipal fire departments with getting a high rating tends to lead them into conformity with requirements of the measuring device. A fire inspection captain succinctly summarized the problem: "They want to see how many men you have and how many fire engines sitting in the fire house. . . . You make sure they like what they see. . . ."

Because of the stress on hardware and manpower in classifying municipalities, municipal fire departments find an indispensable ally in acquiring these things, on the one hand, and an adversary to effective fire prevention programs, on the other hand. A relatively low classification assigned to a municipal fire department considerably strengthens the position of the department in obtaining funds for new staff and equipment. In this respect, municipal surveying for fire protection capability can be an ally of municipal fire departments, especially those that are undermanned and with outdated equipment. . . . However, the same factor severely limits the capacity of the municipal fire department to innovate and establish program priorities anew, as the conditions relevant to fire protection service change. . . .

There is no doubt that insurance evaluation of fire protection has a strong influence on the management of the protection service. There is doubt, however, that this influence has been in the best interest of public fire protection needs. In 1973 Public Technology, Inc., Washington, D.C., was asked by the D1 subcommittee of the National Association of Insurance Commissioners to develop specific proposals for short-range modification of the Grading Schedule as part of a longer-range approach to eliminate the negative effects of the grading schedule on local fire protection. The suggested changes include the following: (1) an introductory statement admonishing that the Grading Schedule should not be used as a standard for fire department planning, (2) reduction of fire flow requirements where sprinklered buildings exist, (3) reduction of water supply and fire department requirements for small cities, (4) some "catchall" requirements (referring primarily to management of water supply and fire department) have been reduced in importance, and (5) pumping capacity of "mini pumpers" has been partially recognized. The ISO has endorsed these changes.

In a publication concerning these changes [2-72], Mr. Porter W. Homer, President of Public Technology, Inc., presents an excellent critique of the Grading Schedule. This publication is recommended reading for anyone who is interested in the effect of the ISO Grading Schedule on municipal fire protection.

## 2.6 BROAD RESOURCE ALLOCATION WITHIN THE FIRE PROTECTION SERVICE

As stated in the introduction to this chapter, fire protection service managers and urban budgetary officers are interested in questions of resource allocation within the fire protection service. For example, the fire service manager may ask, "Is an average response time of three minutes worth the cost in personnel and equipment required to achieve it?" Needless to say, such questions are virtually impossible to answer. The scientist attempts to find answers through models of the overall fire protection system as he perceives it. The professional practitioner looks to careful study and his own experience.

Weitz [2-58] provides an example of the model approach in his advocacy paper, "A Model for the Simulation of Fire Services of an Urban Community." He proposes a comprehensive framework of inter-related submodels for simulation which, if successful, would permit the fire service manager to test decisions related to virtually every phase of fire service management and operation as shown in Figure 2-2. The overall proposal is excessively ambitious. However, some of the submodels described are similar to those which have been simulated by other researchers. (See Section 6.4.)

"Design for the Future" [2-62], a report by the Burbank Fire Department, represents a comprehensive study of fire department needs in an effort to set priorities and plan the allocation of fire service resources. In it the writers have examined the major operations and procedures of their department with particular emphasis on manpower requirements--which account for 90 percent of their budget.

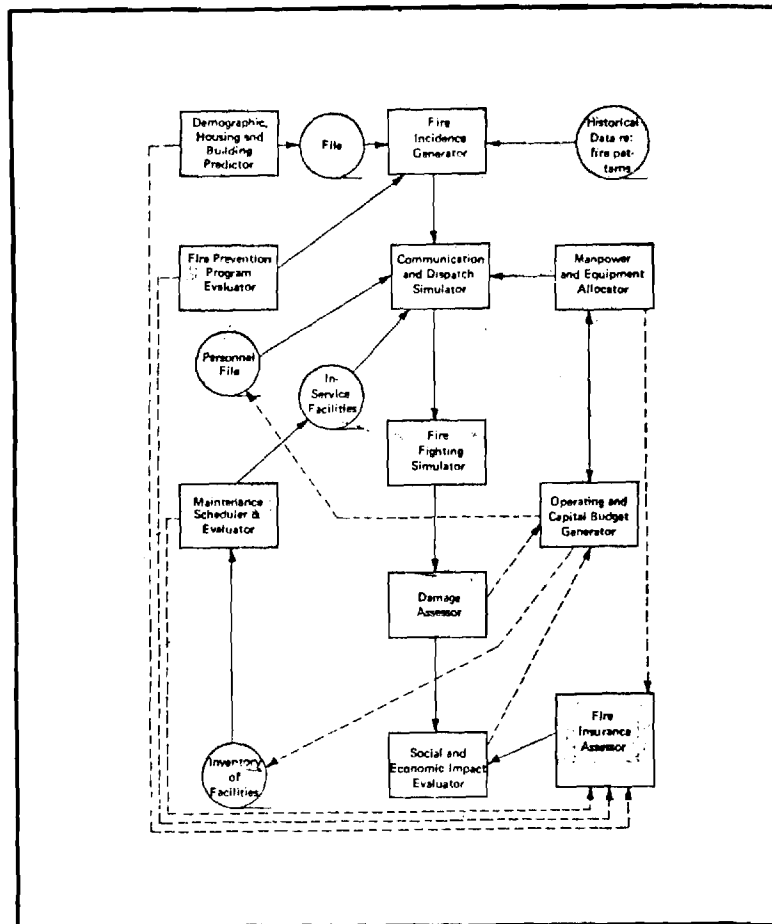


FIGURE 2-2. COMPREHENSIVE MODEL FRAMEWORK  
(Source: Weitz [2-58])

## 2.7 SUMMARY

Fire protection service managers and urban administrators are concerned with problems related to evaluation of fire protection service effectiveness, costs of fire protection, and the relationship between the fire protection service and other urban services. Not all of these, however, are of equal importance. When asked about the practical usefulness of good solutions to the problem, "How can the value of fire department services to the public be measured?" the Professionals Panel was unanimous in responding "Very useful." Other issues (e.g., allocation of fire protection costs, determination of "optimal" quality of fire protection services, economies of scale) were less significant. (The Professionals Panel felt that good solutions to these problems would have "value" or "some value" in practical fire protection work.)

Significant work toward development of productivity measures has been done by Schaenman and Swartz [2-45]. They propose a number of possible measures and "conditioning factors" which may affect those measures. The measures which they suggest have great appeal and, in the words of Chief O'Hagen, Fire Commissioner, City of New York, the work "does present a challenge and a starting point for researchers to develop tools that a chief of any reasonably sized fire department needs so desperately." The research which Chief O'Hagen mentions remains to be done.

The matter of fire protection costs has been dealt with in research on economics of scale, allocation of costs to consumers, and costs of competitive vs. bureaucratic producers. It is difficult, if not impossible, to compare and synthesize this work because of the differences in factors included in the various cost models. Moreover, according to the Professionals Panel, the issues do not have great practical importance.

The only reported research concerned with the relationship of the fire protection service to other local services is Cunningham's study of police-fire integration. This very thorough investigation of "coalescence" in the United States, Britain, and Canada offers empirical evidence that such arrangements are unworkable. However,



a number of "experience reports" cite successful integration of the two forces. It should be noted that these were written shortly after the organizational change was made and that no public information is available as to whether or not integration was successful over the long run. Aside from police-fire integration, little thought apparently has been given to consolidation of other urban services with the fire department. A study by the Burbank Fire Department which recommends that the fire department be given responsibility for building inspections, zoning enforcement, and disaster service is the only exception.

The relationship between the fire protection service and the fire insurance industry has always been quite strong. The ISO Grading Schedule has a major influence on management of most municipal fire departments (except those in Texas). However, there has been no research which attempted to evaluate the consequences of that influence.

As stated earlier in this chapter, every fire chief is interested in measurements of effectiveness and productivity which will help him to provide the best fire protection possible with the funds which he is given. The researcher who wishes to make a useful contribution to fire protection should look at this problem.

In addition to the measurements need, there is another issue which is of great interest to fire service managers. This is the matter of fire codes. According to comments from the Professionals Panel, badly needed legislation must wait for a major catastrophe before it can be enacted. A comprehensive study of fire codes and their effectiveness was suggested.

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## CHAPTER 3

### ADMINISTRATION OF THE FIRE PROTECTION SERVICE

In addition to the management issues discussed in Chapter 2, which are of interest to fire protection management and urban administrators, there are other matters pertaining to administration of the fire protection service. A survey of the literature related to fire service administration indicates three major classifications, as follows: (1) organization, (2) personnel administration, and (3) suppression manpower management. The Professionals Panel considered the last of these to be the most important. However, the literature pertaining to personnel administration offers considerable evidence that this is an emerging problem area.

The general subject of fire service management is discussed by Blum [3-9] in a paper published in 1970. Blum's paper contains much food for thought. He identified a number of fire service problems, some of the most serious being in the area of personnel morale and management. Kimball [3-36], in his paper on "Fire Departments for Small Municipalities," also discussed several administrative matters but emphasized personnel matters.

Several studies of specific fire departments have been conducted and published. Even though the results and recommendations are not directly transferable to other fire departments, these studies will be of interest to both fire chiefs and researchers everywhere. The study which is most likely to be of general interest, due to both results and method of approach, is that conducted by Pinnell-Anderson-Wilshire and Associates under the direction of Col. Paul M. Yeager, Director of Public Safety at Wichita Falls, Texas [A-64]. This study was conducted in three phases, as follows: (1) operational analysis of the existing operations, (2) simulation model development, and (3) systems analysis. The final phase utilized the computerized data base and simulation model in order to develop recommendations for more economical and efficient management.

The project resulted in the following:

- Computerized data base
- Computer-assisted procedure for managing fire prevention activities.
- An evaluation scheme for fire hazzard and fire protection capabilities
- A suggested procedure, including use of the simulation model, for long-range planning
- Recommendations for changes in the insurance rating system
- Techniques for testing some resource allocation strategies

Some of these have been discussed in other sections of this report.

Thompson [A-57], in his dissertation, reported on a contractual study which was performed for San Diego County. The purpose of the study was to analyze the utilization of resources and recommend a strategy of change to improve the overall efficiency of the county's fire protection system. Data were collected from the various fire departments by means of a questionnaire, followed by an interview. Based on a subjective analysis of these responses, Thompson made a number of recommendations regarding consolidation, adoption of standards, adoption of fire codes and more. Unfortunately, both the selection of variables to investigate and Thompson's recommendations are largely intuitive.

Other studies dealing with analysis and evaluation of specific fire service systems include the Orange-Seminole-Osceola Planning Commission study [3-96], the Miami area study [3-95], and the Dutchess County Department of Planning Study [3-97].

### 3.1 ORGANIZATION STRUCTURE

Traditionally, fire department organizations have been paramilitary in nature. The Professionals Panel defended this practice and pointed to at least two benefits: First, discipline is as essential at the fire scene as it is on a battlefield; second, esprit de corps is a major strength of the fire service. The panel agreed, however, that the traditional practice of permitting entry only at the bottom was detrimental to efforts to fill management positions with topnotch men. Most felt that this practice was being abandoned.

The writings and research in the broad area of organizational development are virtually unlimited. Many of these no doubt are applicable to fire departments. However, this evaluation project is restricted to research and related publications pertaining directly to fire protection service management. No attempt is made to include indirectly related, although perhaps applicable, research.

This section will deal first with the various fire department responsibilities which are discussed in the literature and then with research reports which focus on one or more aspects of fire department organization. The matter of organization for fire protection is discussed at length in Municipal Fire Administration [3-104]. This book presents four phases of organization which affect each fire department: (1) internal organization of the department, (2) organization within the municipality or fire district, (3) intermunicipal organization, and (4) organization of municipalities and fire districts in the state.

A logical framework for considering fire department functions is provided by Briffet's report on the Garden Grove fire protection plan developed by Chief Gene Mahoney [3-12]. The objectives of that fire department were, broadly stated, "fire protection" and "rescue service." Fire department operations were categorized as follows:

- Emergency Functions
  - fire suppression
  - rescue service
- Nonemergency Functions
  - administration
  - training
  - fire prevention
  - public education
  - nonemergency functions connected with fire suppression
    - (e.g., routine housework, maintenance of apparatus, servicing, home inspection)

The paper discusses the organization and management of these functions.

Miller [A-38], in reporting on prevention-related research conducted in cooperation with the Atlanta Fire Department, shows five major

functional bureaus for that organization. They are:

- Fire Prevention (inspections and investigations)
- Signal Division (alarm system maintenance)
- Extinguishment Division (suppression and rescue)
- Training Division
- Shop (building and equipment maintenance)

Although the matter of fire prevention is presented in Chapter 7 of this report, there are several papers dealing with organizational aspects of prevention which should be noted in this section. Grant [3-22] reported on the Houston Fire Prevention Division and its activities in the areas of arson investigation and general fire prevention. Darby [3-21] discussed the problems and benefits of the integration and decentralization of fire prevention activity with the operational functions of the Lancashire Fire Brigade.

Some fire departments, in an effort to utilize the fireman's "idle" time, have examined nontraditional functional responsibilities for their organizations. Recommendations that the fire department be given responsibility for (1) building inspections, (2) zoning enforcement, and (3) disaster service were contained in the Burbank study (see Section 2, 3,4).<sup>1</sup> Weller and Hilbish [3-81], writing in 1960, did not advocate nontraditional functions, but cited the reorganization of the Alameda, California, fire department to provide every man with a useful committee assignment in the traditional areas of prevention, training, public education, public relations, civil defense, speakers bureau, photography, preplanning, and the like. In all, there were 31 committees. Unfortunately, it is not known how long this arrangement continued.

Actual research related to fire department organization is limited to two doctoral dissertations. Arslaner [A-3], in 1972, conducted a comparative study of three municipal fire departments. Yahr [A-63] investigated some aspects of organization structure and their relationship or organizational efficiency in a study completed in 1965.

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1. According to a news release in Public Management, June 1964, firemen in West St. Paul, Minnesota, were assigned the duty of inspecting businesses to determine that business licenses were current.

Arslaner's study is conducted at three levels: first, an analysis of organizational structure of municipal fire departments; second, norms and interaction patterns of firemen; and third, individual behavior. The research methodology is described as a multiple-case field study using observation and interviews. The latter were conducted both orally and by questionnaire. After providing a perspective of the political systems in the three cities studied and the social and political environment of fire work, Arslaner's report presents analyses of formal organization of fire departments, organization for fire fighting, recruitment and selection of firemen, socialization of firemen, and firemen's evaluation of their work. Most of the text of the report consists of discussions and inferences drawn from quotations obtained during interviews. Arslaner's conclusions concerning firemen's evaluation of their work roles and the effects of work characteristics on social roles are summarized as follows:

- Firemen tend to assume an extremely defensive posture toward probing efforts into their work roles.
- Firemen tend to assign high importance to their occupation.
- Firemen view their work schedules as generators of a great many difficulties which constrain the performance of their family and social roles.

On the basis of findings reported in the study, Arslaner offers several tentative suggestions for administrative action. They are:

- Improve the recruitment and selection process of personnel by supplying more realistic information regarding the requirements of the fireman's roles and inquire into the applicant's motivation.
- Take administrative action to clarify the incongruity between the traditional work ethic in American society and the requirement of effective fire protection.
- Resolve the social problems which arise on account of the peculiar work schedule.

The discussions in the dissertation are interesting reading and may, as the author intended, provide some insight into basic issues in fire

department organization. However, the Professionals Panel seemed to find some of the results obvious and to disagree with the remainder.

Yahr investigated the relationships between several aspects of organizational structure (i.e., size, departmentalization, levels of authority, administrative component size, and centralization) and the effectiveness of fire department organizations. The effectiveness measure which Yahr used in his study was the fire department subscore in NFBU rating.

The general procedure for investigating the relationships of interest consisted of determining the association between size, departmentalization, etc., while controlling for any differences in the measure of resources (expenditures) in relation to the requirements for service. This was an effort to recognize that some departments might be more effective because they had more resources rather than because of any organizational difference. A statistical analysis was performed using data from 32 municipal fire departments located in the U.S. The conclusions of the study may provide general information to the fire chief, but they are not action-oriented. (See Table 3-1.) Also, the use of the NFBU rating as a measure of fire department effectiveness is questionable since, as pointed out in Section 2.5, the grading process is concerned with quantity -- not quality.

The Professionals Panel appeared to have only moderate interest in the matter of organization. At the same time, however, they admit to problems in the area of personnel motivation and public relations. Quite obviously, they did not feel that these problems were related to organizational structure. Well-conducted research to examine the depth and cause of the problem -- including any relationship to organization -- would be a valuable contribution.

Hickey, in 1969, investigated several questions concerning the operation and management of fire department organizations [A-17]. More specifically, the study dealt with how fire department officers perceived their involvement in the management functions of organizing, planning, directing, coordinating, controlling, and communicating. Information was obtained by questionnaires sent to officers in paid fire departments,

TABLE 3-1. CONCLUSIONS OF YAHR'S STUDY

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1. The administrative component is unrelated to organizational size and departmentalization.
  2. The administrative component is positively correlated with levels of authority.
  3. Departmentalization is positively related to levels of authority.
  4. Among organizations pursuing the same general formal goals, e.g., fire fighting and fire prevention, size is positively related to departmentalization.
  5. Organizational size is not related to levels of authority.
  6. Organizational size is positively related to area of specialization.
  7. Organizational size is not related to organizational efficiency.
  8. Departmentalization is positively related to organizational efficiency.
  9. Levels of authority are not negatively correlated with organizational efficiency.
  10. There is no relationship between the administrative component and organizational efficiency.
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volunteer fire departments, and combination fire departments. In addition to this stratification by type of fire department, the sample was stratified across eight city population groups. Each officer was asked to indicate the amount of time he believed himself to be devoting to each of 57 management activities.

Analysis of these responses led Hickey to the following conclusions concerning the professional posture of the fire department officers surveyed:

- (1) Fire department officers perceive a high level of involvement in the identified functions associated with managing organizations.
- (2) Fire department officers do not perceive their involvement with the identified management functions to be in accordance with modern organizational theory.
- (3) Fire department officers cannot be stereotyped as principally individuals involved in fire suppression.

Due to the study's findings, Hickey recommended that officer training programs give cognizance to methods of modern management, such as program budgeting, data processing, work measurement, personnel management, and systems analysis and organization.

Conclusion No. 2, which gave rise to the training recommendations, is a statement of judgement made by Hickey. It would be interesting to see if officers really perceive a need for the recommended training. Comments made by the Professionals Panel indicate that they do perceive such a need.

### 3.2 PERSONNEL ADMINISTRATION

There are many topics which could be classified under the general subject of personnel administration. As in the case of organizational theory and development, there is a vast literature concerning personnel practices and administration, much of which is useful in fire protection service and administration. This evaluation project made no attempt to examine such literature. The literature search, however, disclosed research reports and/or other papers dealing with matters related to personnel administration specifically in the fire protection service.



Kimball's paper, "Fire Departments for Small Municipalities" [3-36], is quite general in nature. Most, however, deal with one or more of the following:

- Selection and promotion
- Training and education
- Labor relations
- Compensation

The majority of the Professionals Panel, primarily chief officers, felt that only the last of these was a serious problem. Some members, however, felt that problems were emerging in the other areas. These problems, centered on morale and motivation, were aggravated by present-day public attitude toward firemen.

In a paper published in 1970, Blum [3-9] also perceived this problem. He wrote the following:

Firefighters are increasingly disturbed because their traditions, and the values they represent, appear to be disintegrating. Changing public attitudes, deteriorating relations with minority communities, and a trend toward bureaucratization have dimmed the luster of the job and shaken and transformed many firefighters' self image.

It seems safe to conclude that fire departments are faced with increasing problems having to do with personnel selection, training, motivation, and compensation.

### 3.2.1 SELECTION AND PROMOTION

The fire protection service is unique in terms of personnel requirements. Its fire-related missions are to prevent economic loss and human suffering through prevention of fires and quick extinguishment of those which do occur. Moreover, nonfire missions are almost always emergency-oriented. For these reasons fire departments are organized and trained to serve in crises. There is no other urban service which places such demands on its personnel.

Over many years, fire service personnel have been a proud fraternity, linked by tradition, dedication, and self-sacrifice. The individual fireman was an honored hero in his community. The true depth and social value of the traditional esteem in which the fireman has been held is attested to by the fact that in many smaller cities volunteer firemen

serve without pay. As long as these traditions persisted, both on the part of the public and on the part of the firemen, there was no cause to question or to examine the methods of personnel selection and promotion. Whatever they were, they appeared to be working well. However, the situation has changed considerably in recent years. Respect for the firefighter has been replaced with "Burn, baby! Burn!" This change seems to typify the erosion of public admiration for the fire service. Obviously the problem is rooted in social ills which have no origin in the fire service and which are not curable by the fire service. Fire service problems are none the less real.

The loss of self-identity and satisfaction has affected the fire fighter's morale and led to a rise in militancy. Demands have been made for higher salaries and better working conditions. Criticism has been directed at traditional criteria for entrance and promotion. Minority groups, in efforts to enforce their rights, have challenged the disproportional number of whites in urban fire departments.<sup>1</sup>

Personnel testing and selection methods differ from state to state and city to city.<sup>2</sup> Most, however, require that the candidate pass a written test designed to determine general intelligence and mechanical aptitude. The validity of fire service examinations in general has been attacked from many quarters. "The Report of the National Commission on Fire Prevention and Control" states:

As we indicated earlier, entrance requirements for the Nation's fire departments also vary widely, and too few tests meet the Federal requirements that they be related only to the performance requirements of the job applied for. Because of the conservative hiring and promotion practices of fire departments, too many training programs, together with greater willingness of departments to hire at all ranks from outside, would diminish the need for this emphasis. A fair

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1. It is true that these problems do not exist to the same extent in all municipal fire departments. The fire chiefs in the Professionals Panel recognized the problems, but stated that they were not yet serious matters in their own departments.
  2. Municipal Fire Administration, International City Managers Association, states that the Public Personnel Association and some private consulting organizations publish tests specifically designed for entrance-level fire fighters.

job-related test, which the Joint Council of National Fire Service Organizations is now working on, will, in turn, create pressures for better training and more liberal hiring and promotion practices.

Other criticisms of the tests claim that their questions presume every fireman will eventually be a contender for fire chief.

One of the research questions which the Professional Panel thought to have greater policy utility was, "What are some predictors of vocational success which could assist in the selection of personnel?" Marks [A-37] explored this question in his doctoral research conducted at the University of Southern California. Specifically, he sought to locate predictor variables which could be useful indicators of vocational success in municipal fire service. After some study, Marks chose to use the judgment of the fire training officer to obtain a measure of vocational success. This was done by asking the fire training officer to rank-order the fire fighters from best to worst. The rationale was that the fire training officer was the one person who knew all the men.<sup>1</sup> The instrument used to obtain personal background information was the Personal History Index available at the University of Chicago. The Personal History Index consists of 87 items, each of which asks a question about the individual's family, education, and work experience. The scores are analyzed to obtain measures of eight performance factors, as follows:

- (1) School Achievement
- (2) Higher Education Achievement
- (3) Drive
- (4) Leadership and Group Participation
- (5) Financial Responsibility
- (6) Early Family Responsibility
- (7) Parental Family Adjustment
- (8) Stability

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1. Marks cites a study by Jarret [3-31] which found that the fire training officer was the best person to rate all the fire fighters. Rating by any other individual was held to introduce fire station to fire station and shift to shift bias.

The Personal History Index was completed by a total of 200 fire fighters in 10 California cities. In each location the fire fighters were ranked by their training officer and questionnaires sent to the top 10 percent and the bottom 10 percent of the rank-ordered names. The scores on the Personal History Index were then studied to determine if there was a difference between the two groups with regard to the above performance factors. Results indicated statistically significant differences between the two groups (top 10 percent and bottom 10 percent) with regard to (6) Early Family Responsibility, (7) Parental Family Adjustment, and (8) Stability.

Marks points out several limitations of the study: (1) the small sample size, (2) inclusion of "fire fighters" only, (3) consideration of urbanized metropolitan areas only, and (4) the limitation of the self-administered questionnaire. To these should be added the fact that fire training officer ratings were assumed to be a valid measure of vocational success. The Professionals Panel did not agree with this assumption.

Although there is a need for improved instruments for selecting fire service personnel, this study is not sufficient as a basis for the development of such instruments. It does, however, serve to point out the directions in which further work should be done--validation of the results and the development of a suitable test instrument.

Other studies which have dealt with characteristics of firemen are those of Jarrett [3-31] and Matarazzo [3-53]. Jarrett examined the question, "Does a man who believes that self-reliance is important in being a successful fire fighter make a better fireman than one who does not hold this conviction?" Evidence of a "yes" answer was somewhat weak. Matarazzo studied 243 successful applicants for policeman and fireman jobs. His sample indicated that these individuals had intellect and personality adjustment. The study was not work-oriented and offers no help in personnel selection.

Arslaner's study of three municipal fire departments contains a chapter dealing with two subjects which are relevant to recruitment and selection of firemen. The first concerns practices and their consequences, while the second concerns selected characteristics of the

individual fireman. In regard to recruitment, Arslaner examined the early applicants vs. late applicants for fireman positions and the possible consequence of a procedural change to virtually eliminate the waiting period before the applicant takes the entrance examination. Several conjectures are made, but no conclusions can be drawn. The processes of selection in the three cities were examined and criticized. Concerning both recruitment and selection, Arslaner stated, ". . . the fundamental deficiency of the process has to do with neglecting the most relevant organizational factors of the work environment. An effective selection process should be based upon an understanding of the work environment, on the one hand, and the expectations of potential fire fighters, on the other hand." Arslaner's inquiry into motivation for choosing a fireman's job led him to conjecture that, for a large proportion at least, the opportunity to engage in "moonlighting" is an important factor.

The studies discussed above are apparently the only research dealing with personnel selection for fire protection service. There are, however, a few publications which describe present practices and/or advocate modifications to present practices. The California Fire Chief's Association adopted, in 1966, minimum standards for fire service personnel recruitment, training and education. In their study regarding organization, operations, equipment, and manpower needs, [3-89] the Burbank Fire Department advocates psychological and/or psychiatric testing of candidates.

The matter of personnel recruitment and selection is admittedly a matter of concern. For the Professionals Panel, however, the concern was that social issues are becoming more forceful than sound practice. For example, the report of the National Commission on Fire Prevention and Control [3-85] contains the following statement:

In the administering of Federal funds for training or assistance to local fire departments, the Commission recommends that eligibility be limited to those departments which have adopted an effective, affirmative action program related to the employment and promotion of members of minority groups.

It is incorrect, however, to infer from this recommendation that the

Commission advocates the hiring of applicants without regard to their qualifications and potential. What obviously is needed is defensible, job-related criteria and specifications for selection of fire service personnel.

### 3.2.2. TRAINING

This subsection is concerned with management and innovation in training. The scope and content of training needs in the fire service constitutes a field of technology which is not considered appropriate for this evaluation study. It should be noted however that the nature of fire protection activities implies a need for training in many areas. Foremost is the technical training for fire extinguishment. In addition, firemen must be trained in fire prevention activities, fire loss prevention, burn and injury treatment, rescue tactics, and safety. They must know how to handle the victims of fire and to evacuate frightened crowds from burning buildings.<sup>1</sup> In order to maintain his skills, the typical fireman in an urban fire department spends many hours in training. According to the Burbank Fire Department report, "A Design for the Future" [3-89], the Burbank fireman spends approximately 10 hours per week participating in scheduled training activities. No estimate of the cost of training are available. However, fire department operations in the U.S. cost approximately \$2.5 billion annually [3-85], and the manpower costs have been estimated to be as much as 95 percent of the cost of a public fire department [A-19].

Apparently, there are no studies which deal with the training needs of fire protection services. Training and education in the fire services was the subject of a symposium conducted by the Committee on Fire Research of the National Research Council in 1970 [3-115]. The stated aim of the conference was to make a critical review of current practices, to explore areas in which improvements could be made, and to encourage reexamination and improvement in the area of training. No

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1. A discussion of training needs is found in "What the Fireman Needs to Know," by Lyle L. Goodrich, as published in the proceedings of a symposium conducted by the Committee on Fire Research of Engineering, National Research Council [3-115].

recommendations or conclusions resulted from the conference other than those contained in individual papers.

A number of experience reports and advocatory papers have appeared in various publications. These include descriptions of fire fighters' training techniques and equipment [3-111], [3-112], [3-1], [3-29], [3-72], [3-79]; discussions of specific training programs [3-118], [3-63], [3-51], [3-105], [3-71], [3-98], [3-99]; evaluation of training [3-83]; the use of programmed learning materials in training [3-25], [3-59]; the use of "planning games" in training [3-8]; methods of training course development [3-44]; and discussions of training needs [3-10], [3-43], [3-89], [3-104].

The importance of training and education in fire protection is recognized in legislation now before the U.S. Congress. Known as the Fire Prevention and Control Act of 1974, this legislation incorporates the recommendations of the National Commission on Fire Prevention and Control which were published in May 1973. The bill provides for a national agency, the United States Fire Administration, and the establishment of a National Fire Academy for education and training. This institution would develop and conduct educational programs of its own and also assist state and local training and educational programs. A discussion of some of the provisions of the act and their importance is contained in the paper "Fighting Today's Fires" by W. Howard McClelland [3-104].

### 3.2. LABOR RELATIONS

The area of labor relations in the fire protection service has received very little research attention. Only one research report was found during the literature search for this evaluation project. Oswald [A-1] in doctoral research at Georgetown University, examined the question "Is compulsory arbitration a proper tool of public policy?" through a study of the experience of the International Association of Fire Fighters. In this work, Oswald analyzed experiences with compulsory arbitration in Canada, the United States, and a few foreign nations. He identified the bases on which arbitration decisions were made and the legal edges

It is i

Oswald found that U.S. organized labor, in general, does not look with favor on compulsory arbitration. The stated reason is that the prospect of resolution through compulsory arbitration weakens the bargaining efforts. U.S. policy, opposed to compulsory arbitration in the past, appears to be slowly changing. In the case of fire fighters, the use of compulsory arbitration seems to protect two sometimes divergent interests (e.g., the fire fighters' interest in collective bargaining and the public interest in uninterrupted fire protection). Oswald found no evidence that the collective bargaining process was weakened by compulsory arbitration; rather, it appeared to strengthen bargaining power.

Concerning wage issues, Oswald found that "On the basis of statistical tests, there is no indication that fire fighter's wages change significantly with or without compulsory arbitration." He concludes that "Compulsory arbitration is not the answer to all labor relations impasses, nor to all governmental employee-employer disputes." He adds that "Compulsory arbitration is regarded as a last resort in an area of employment or service where continuous operation is absolutely essential in the public interest."

Oswald's study seems somewhat academic. As he stated, both union leaders and fire service managers prefer to avoid strike issues and to settle those which do arise through negotiations. When differences cannot be resolved by negotiations, rational thought favors any mechanism which avoids a strike.

The Professionals Panel seemed to be in general agreement that the International Association of Fire Fighters was a constructive force in fire protection. The chiefs do not feel that labor relations is a problem area.

#### 3.2.4. COMPENSATION

Data on fire department salaries and expenditures, as well as other fire department data for cities over 10,000 in population, are regularly published in the Municipal Year Book, International City Managers Association, Chicago [3-90], [3-91]. These data permit comparison among cities. Although there are disparities in fire fighters' pay among cities



of approximately the same size, the differences are usually explainable and have not emerged as an issue. Currently, however, the fire fighter is upset by disparity between his pay and wages paid to others with whom he compares himself.

Craft [3-18], in a paper published in the Labor Law Journal, discussed wage disparity as a cause of a claimed increase in fire-fighter militancy. According to Craft, the IAFF and its leaders argue against disparity between fire and police salaries on the basis that it will result in low-quality fire service personnel. He states, however that there are two more fundamental reasons why disparity is an issue. They are: (1) loss of occupational status attached to disparity and (2) loss of a powerful economic lever for wage improvement if disparity is accepted.

Craft used data from the Municipal Year Book, 1939-1970, to show a trend towards disparity between police and fire fighters' salaries in the 1961-1970 period. Table 3-2 from Craft's paper shows salary ratios for fire fighters and police patrolmen. The ratios were obtained by dividing the median entrance salary for fire fighters by the median entrance salary for police patrolmen. Thus, these ratios express the fire salary as a percentage of corresponding police salary. Craft concluded that the apparent disparity was an important factor affecting the emergence of fire-fighter militancy but predicted that the disparity issue would decline in importance in the larger cities. It was his contention that larger cities would soon need to pay parity wages in order to attract qualified fire fighters. He predicted that disparity would continue to be an issue in medium-sized and most small cities.

A study made in 1963 by William F. Danielson, Personnel Director, City of Berkeley [3-20], compared police and fire services with respect to (1) retention and turnover, (2) recruitment, and (3) work content and working conditions. The conclusions of the study were that Berkeley police patrolmen should receive higher salaries than fire fighters.

Berrodin [3-6], in a paper reporting on the comparison of police and firemen's salaries in Michigan, reported that there had been little controversy over the steady increase in the number of cities with disparity in favor of the policemen. He cited several reasons for the

TABLE 3-2. SALARY RATIOS FOR FIRE FIGHTERS AND POLICE PATROLMEN\*

Year	City Size (000's)					
	(Size 1) Over 500	(Size 2) 250-500	(Size 3) 100-250	(Size 4) 50-100	(Size 5) 25-50	(Size 6) 10-25
1939	1.00	1.00 <sup>a</sup>	1.01 <sup>b</sup>	.99 <sup>c</sup>		
1940	.98	.98 <sup>a</sup>	.97 <sup>b</sup>	1.00 <sup>c</sup>		.99 <sup>d</sup>
1941	.99	.99 <sup>a</sup>	.99 <sup>b</sup>	1.00	1.00	.99
1942	1.00	1.02	1.03	1.01	1.00	.98
1943	1.02	1.01	1.00	1.02	.96	.94
1944	.94	1.02	1.01	1.01	.98	.97
1945	.91	1.01	1.00	1.02	.99	.99
1946	1.02	.99	.98	.97	.99	.99
1947	.96	.96	1.02	1.00	1.01	.99
1948	.98	1.00	1.00	1.01	1.00	.99
1949	1.00	.97	1.00	.98	1.00	.92
1950	1.00	1.00	.98	.99	1.00	.99
1951	.97	1.00	1.00	.99	1.00	.98
1952	1.00	1.00	1.04	.97	1.00	1.01
1953	1.01	.98	.99	1.01	1.00	.98
1954	1.00	1.00	1.00	1.02	1.01	1.01
1955	1.01	1.00	.99	.99	.98	.99
1956	1.02	1.00	.98	1.01	.99	.99
1957	1.04	1.00	.99	1.00	1.00	1.00
1958	.99	1.00	1.01	1.00	.99	.98
1959	.94	.99	1.00	1.00	1.00	.99
1960	1.01	1.01	.99	.99	.99	.97
1961	1.00	1.00	1.00	1.00	1.00	.97
1962	.99	.97	1.00	.98	.99	.96
1963	.97	1.00	.98	1.00	1.00	.97
1964	1.00	.98	.99	.97	.99	.96
1965	1.06	.97	1.00	.99	1.00	.95
1966	.99	1.01	.96	.97	.98	.96

TABLE 3.2 (CONTINUED)

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Year	City Size (000's)					
	(Size 1) Over 500	(Size 2) 250-500	(Size 3) 100-250	(Size 4) 50-100	(Size 5) 25-50	(Size 6) 10-25
1967	.99	.99	.98	.99	.97	.96
1968	1.01	.92	.98	.98	.98	.94
1969	1.04	1.04	.97	1.01	.98	.98
1970	1.00	.97	.97	.98	.99	.95

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SOURCE: Data for the ratios were obtained from Municipal Year Book, International City Managers Association, Chicago, Annually, 1939-1970. Fire Fighter salary data were obtained from the section entitled "Fire Department Statistics" and Police salary data from "Police Department Statistics." (A blank space indicates that information was not available.)

\* Data rounded to two decimals.

<sup>a</sup> Cities included are from 200,000 to 500,000 population.

<sup>b</sup> Cities included are from 100,000 to 200,000 population.

<sup>c</sup> Cities included are from 30,000 to 100,000 population.

<sup>d</sup> Cities included are from 10,000 to 30,000 population.

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(Source: Craft [3-18])

trend:

- greater difficulty in selecting and training qualified police officers
- work week and duty time differentials
- greater differences in promotional opportunities for fire fighters

He also cited a Madison, Wisconsin, study made by the Public Administration Service which advocated a salary differential for policemen, using much the same arguments as given above.

Buck [3-13], in a follow-on article to Berrodin's, argued that there was no justification for disparity and that, in the long run, it would cause problems. His arguments are largely a rebuttal of Berrodin's.

The issue of parity between policemen's and fire-fighters' salaries does not appear to be settled. Furthermore, it seems highly inappropriate that, as a general issue, it should be. There can be no "general rule" either way. Pay for any job depends upon a number of job factors, such as knowledge required, problem-solving requirements, working environment, and accountability. The literature survey failed to turn up a single report of a careful job evaluation study of the type which any well-managed industrial firm would use for establishing pay differentials among jobs. There is no apparent need for research in this area, but it does appear that job evaluation should be used to establish a pay scale for all municipal employees.

### 3.3 SUPPRESSION MANPOWER MANAGEMENT

Section 3.2 dealt with topics in the general area of personnel administration. In this section, research reports and related publications dealing specifically with suppression manpower management will be discussed. According to the Professionals Panel and other fire service professionals, this topic is highly important. Questions of major interest are: (1) How should equipment be manned so as to avoid waste of manpower and yet provide effective suppression effort? and (2) How should manpower schedules be arranged?

### 3.3.1 COMPANY MANNING POLICIES

Company manning decisions find the fire chief on the horns of a dilemma. The ISO grading is based upon a specified distribution of fire stations and manning of companies, and there is ample evidence to support the validity of the specified strength of companies. Thus, there is considerable pressure to meet these manpower requirements. On the other side, however, the fire chief is almost always short of funds and pressured to reduce costs.

Publications concerning manpower needs indicate general agreement with the National Fire Protection Association statement that "a 4-man crew on a pumper is only 66% as effective as a 5-man company, and a 3-man crew is less than 25% as effective as a 5-man crew."<sup>1</sup> Spillman [3-75] reported a study by the Dallas Fire Department which consisted of a series of tests in an effort to determine comparative effectiveness (in terms of time to water application) of various manpower levels in performing routine fire ground operations. The comparative results for three of the tasks are shown in Table 3-3. The Dallas study can be criticized from the standpoint of internal validity because of the small sample size (each operation was conducted a minimum of four times for each level of manpower) and apparent lack of statistical validity. However, the results are consistent with the NFPA statement and with the experience of the Burbank Fire Department as reported in "Design for the Future" [3-89]. The Burbank report makes the point that manning standards are dependent on factors which differ from city to city and that what is right for one city may not be right for another. They consider four-man companies to be an acceptable minimum for their situation. The Burbank report makes another important point not mentioned by Spillman but which supports the argument for adequate manning. Concerning undermanned companies, the report states: "In addition to the reduced protection provided, we get into serious questions of safety plus increasingly inefficient use of manpower." Unfortunately, the matter of fireman safety seems to be neglected in the research disclosed by our survey.

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1. NFPA Handbook, 12th Edition, p. 10.

TABLE 3-3. COMPARATIVE EFFICIENCIES OF FIRE CREWS

Task Description	Size of Crew			
	3	4	5	6
1. Single engine advancing line; and operating on 3rd floor of a large building	27	47	79	100
2. 65' aerial truck company operation at typical working fire in commercial building	30	49	81	100
3. An engine company using a pre-connected line and performing a rescue	55	88	100	Not used
4. Combined operation: Two engine companies and one truck company at a typical fire	39	60	79	100

(Source: Spillman [3-75])

Kimball [3-33], [3-38] also points out the importance of adequate manning and claims that "the vast majority of fire departments lack enough men on duty to do a good job on fires more serious than those in ordinary single-family dwellings." He advocates fewer, well-manned companies as opposed to undermanned units with one, two, or three men on duty.

City managers, and often the general public, feel that when companies are adequately staffed, manpower is "wasted" because fire fighters spend a relatively small proportion of their duty hours in actual fire extinguishment. The problem has been around for a long time and, judging from the similarity of comments made over a decade ago and comments made recently, it may be around for a lot longer.

Bean and McCalla [3-4] in 1961 argued that fire department organization and manning policies were archaic and no longer tolerable. They pointed out that the San Diego two-platoon system and 63-hour week means that in a calendar year's 365 days, a fireman is off duty 240.6 days and on duty only 124.4 days. Moreover, they claimed that over 67 percent of a fire fighter's time was unproductive. Some 14 percent was spent on housekeeping duties required by the "live-in" system. Only 19 percent of the time was considered productive and only 1.3 percent was needed for answering alarms.

In a 1913 statement to the National Commission on Fire Prevention and Control, Howard Boyd [3-10], Fire Marshal in Nashville, is quoted as follows: "There is probably no greater waste of manpower in this country than the fire fighter sitting in the station waiting for an alarm!" Various solutions to this dilemma have been proposed and, in some cases tried. Bean and McCalla propose consolidation of police and fire services and assembly of fire-fighting forces at the fire scene rather than maintaining readiness at the fire station. Cunningham [A-12], in his study completed in 1968, cited several cases where this arrangement was tried with near disastrous results. Boyd's recommendation to the National Commission on Fire Prevention and Control was that the fire fighter's "waiting time" be utilized in public education activities and fire prevention. Concerning implementation of his recommendation, Boyd

stated the following:

It is doubtful if changes can be accomplished unless or until the Insurance Services Office changes its policy on the grading schedule.<sup>1</sup> Few fire chiefs are going beyond that for which the ISO will grant credits - and 750 points for prevention, out of 5,000, do not offer much inducement. The caliber of the fire service is determined largely by the insurance companies.

Reports on the use of "special squads" to reduce total manning requirements have been made in a few cities. Paddock [3-60] reported the use of a "Flying Squad" in Orange, California. This unit consisted of a specially designed vehicle and two men per shift who were centrally located. They responded as backup to alarms anywhere in the city. Cookingham [3-17] reported the use in 1961 of a similar, but more heavily manned, "hot shot squad" in Fort Worth, Texas. Also, a 1963 report [3-118] describes a special "snorkel squad No. 1" in Chicago which served principally as a rescue unit.

Judging from comments of the Professionals Panel and what has been written concerning company manning, most companies should carry a complement of four to five men. Savings in manpower, then, must come from improvement in methods and equipment and more effective prevention efforts. An issue which seems equally important is the effective use of the approximately 98 percent of a fireman's time which is spent on activities other than responding to alarms. An analysis of alternatives that have been tried and their success (or failure) would be very useful.

### 3.3.2 MANPOWER SCHEDULING

One of the problems (and also one of the fringe benefits) of a fire fighter's job is the 24 hours on - 24 hours off schedule. This arrangement seems to be traditional in most large city fire departments. However, this duty schedule, coupled with the push for a shorter work week (now 56 hours or more in many cities), presents a problem for managers of fire protection services. Moreover, it is known that the likelihood of a fire is not constant across days of the week or hours of the day<sup>2</sup>. The published literature does not indicate, however, that any

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1. Insurance evaluation of fire protection is discussed in Section 2.5.

2. Occurrences of alarms is discussed in Section 5.2.1.



attempts have been made to schedule fire department manpower in proportion to expected demand. For all of these reasons, it appears that present scheduling practices could be improved

The only research related to this general problem is Heller's work [3-30] on proportional rotating schedules for policemen. The scheduling problem for police is distinctly different from that for the fire service. However, since the study is particularly concerned with scheduling police patrol forces whose major function is responding to calls for service from the public, it may have some implications for the fire service. Since Heller's research deals specifically with police scheduling and requires major changes for use in fire service scheduling, it was not evaluated with regard to internal validity and is referenced here among "Other Related Papers." It would be very worthwhile if a similar study were made for scheduling of firemen.

#### 3.4 SUMMARY

Administration of fire protection service, as a general area, was perceived by the Professional Panel to be reasonably well off. There are, however, darkening clouds on the horizon and one of them may be the nature of fire protection service management itself. The Report of the National Commission on Fire Prevention and Control [3-85] recommends a blending of "leadership" with "management expertise." It states that:

Most American fire departments are strong in leadership and weak in management expertise. The typical hiring and promotion system - in which everyone from the chief on down started as a rookie firemen - has guaranteed good leaders who understand the men under them and are respected by their subordinates. But fire departments could profit from competition for certain leadership positions from outside fire departments. They need qualified planners whose expertise lies in fire protection engineering, operations research and systems studies rather than fire fighting. This is especially true in larger departments where, further, specialists in budgeting, personnel, and community relations need not be fire fighters.

It is reasonable to expect that the Commission's recommendations will have an influence on fire protection services in America and that fire service management will gradually change. Blum [3-9] also

emphasizes the need for management changes. He points out that many cities have large fire departments and that there are growing concerns with costs, labor relations, force deployment, and community relations which make it increasingly important that fire officers be trained as managers.

Fire service administration has not had the benefit of research. Some work has been aimed at discovering basic psychological and background characteristics of individuals who make good fire fighters. However, no test instruments have been developed and the work is academic as far as fire chiefs are concerned. In other areas of personnel administration, only scattered experience reports and advocacy papers are to be found. For the most part, these papers serve mainly to emphasize the need for thorough study. This seems to be particularly true in the areas of training and job evaluation.

Suppression manpower allocation is the administrative area with the greatest policy utility implications -- according to professionals attending the San Francisco NFPA Seminar and Workshop. (Appendix C.2) Since manpower costs account for approximately 95% of fire department operating costs in many cities, it seems that their evaluation is correct. There is clearly a need for research in the area of company manning and manpower scheduling.

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## CHAPTER 4

### FIRE INFORMATION AND COMMUNICATIONS SYSTEMS

The literature search for this evaluation study disclosed a variety of design reports, advocacy papers, and experience reports dealing with various subjects in the general area of fire information and communications systems. These systems, of course, are greatly dependent on technology which has changed rapidly and drastically in the last decade. In fact, much of the innovation appears to have been accomplished within the last five to six years. As a result, papers written prior to the mid 1960's are usually outdated.

Examination of recent publications indicated that they could be classified in the following subject areas:

- Broad management information systems
- Fire reporting systems
- Dispatch-control systems
- Fire communications systems
- Traffic signal control systems

Very little policy-related research was found in any of the subject areas. For the most part, the principal research underlying information communication systems is technical, hardware-oriented, and outside the scope of this study.

The Professionals Panel agreed that the general area was important and were particularly interested in broad management information systems.

#### 4.1 MANAGEMENT INFORMATION SYSTEMS

"Design for the Future," a report by the Burbank Fire Department [4-63], discusses the need for information processing:

Rapidly changing environmental, attitudinal, and technological factors are combining to present an ever-widening challenge to the Fire Service. There has been and will continue to be an explosive informational in-

crease. In order to meet this challenge, the Fire Service must make a broad analysis of its position as a service organization and then establish policies to meet the challenge.

Information is the cornerstone upon which a successful organization is built. Information is vital if the functions of planning, decision, and control are to be effectively executed. There is no advantage to collecting information if it is to be filed and not used to advantage. This is the position the Burbank Fire Department is in today, having a large store of information that is beyond effective analysis with the facilities at our disposal.

We are on the threshold of an electronic data processing era which portends tremendous possibilities for informational processing and usage. The computer age is here.

These comments, made in 1970, describe the status of most larger city fire departments at that time. Actually, however, the design and installation of computer-based information systems for the fire protection service had already begun. In fact, the chronology of the development of computer-based management information systems for the fire service began in the mid 1960's.

Briffett and Mitchell [4-10], in 1966, described the South Gate Municipal Management Information System (Project SOGAMMIS) and its implications for the fire department. An advocacy paper by Gaade [4-22], in 1968, discussed computer uses in fire service and emphasized the need for and potential benefits of an integrated data processing system. Briffett and Kardell [4-8], in the early 1970, described design concepts for a fire department reporting and information system to include the following functional activities:

- Fire prevention
- Fire suppression
- Fire investigation
- Supportive functions

In their concluding remarks, they state:

Too few fire departments are using the facility of existing computer installations in their respective cities. Where computers are being used, only limited applications

have been evident. Some of these users are Los Angeles, Mountain View and Riverside in California; Seattle; State Fire Marshal in Oregon; Tucson, Arizona; Windsor, Ontario, Canada; New York; Wintson-Salem, North Carolina; Wichita Falls, Texas and perhaps others. Within the next two years, the cities of Long Beach, California, Charlotte, North Carolina, and also Wichita Falls, Texas will have developed Public Safety subsystems (Fire-Police-Civil Defense) under contract to the Department of H.U.D. in Washington.

In October 1971, Gaudette and Harrington [4-25] presented a case study of an information system which had been developed for the city of Cambridge, Massachusetts. Their system was designed specifically for the purpose of facilitating quantitative analysis of fire problems as an aid to planning and decision making.

Also, during the late 1960's and early 1970's, computer-based management information system design activity was in progress at the RAND Corporation in New York City. Working with IBM and the New York City Fire Department, RAND prepared a functional definition of a computer-aided management information and control system [4-2]. They envisioned a system which would provide for real-time interaction in the dispatching process and in deployment. In addition, it would routinely record, store, and compile data necessary for management control and provide records and information about department operations in a manner suitable to facilitate decision making. This initial conception of an "ideal system" has provided a framework for design of economically feasible segments.

At approximately the same time these systems were being designed and implemented, two major urban management information systems design efforts were undertaken. In Connecticut, the Advanced Systems Development Division of IBM initiated, with the City of New Haven, a joint study to explore the application of computer technology to urban government [4-81]. Some thirty departments, agencies and services were studied and proposals were made for an integrated data system. The conclusion of the study was that a computer-based integrated municipal information system would be more likely to achieve major benefits than nonintegrated, function-oriented systems. A similar project in Burbank, California, produced much of the same conclusion. The results of these projects led to the

establishment of the Urban Information Systems Inter-Agency Committee (USAC), consisting of nine federal agencies and headed by the Department of Housing and Urban Development. In order to encourage further development of urban management information systems, USAC in 1969 invited cities with populations between 50,000 and 500,000 to submit proposals for support of either:

- (1) The development of an integrated municipal information system to encompass all of the common functions of the municipality, or
- (2) The development of one of four specified subsystems supporting public finance, public safety, human resources development, or physical and economic development.

The Charlotte Integrated Municipal Information System Project [4-58] is one of the projects which was completed under the USAC program. The Fire Operation Module of the Charlotte Information System is concerned primarily with providing information of fire-fighters at the scene of an alarm. Specifically, the module provides for on-line storage and retrieval of critical fire support data for each building for which an inspection report has been entered into the system. A schematic representation of the fire operations module is shown in Figure 4-1. The data input is obtained from the Building Record shown in Figure 4-2. In addition to the fire operations module, the computer-based management information system for the Charlotte Fire Department includes a fire reporting system and a fire prevention reporting system. These provide data and trend analysis for management decisions.

A second project sponsored by USAC is the Public Safety Subsystem for the City of Long Beach, California. The final report for this project was not available at the time of our literature search. However, the Conceptualization Task Completion Report [4-73] describes the fire components of the Public Safety Subsystem. The four operational components discussed are: (1) dispatch, (2) suppression, (3) prevention, and (4) investigation.

The National Fire Protection Association, under contract to HUD, has developed and implemented a uniform fire incident reporting system (UFIRS). This system is based on NFPA Standard No. 901, "Uniform Coding for Fire Protection" and, according to a 1973 report by Granito [4-27], it is

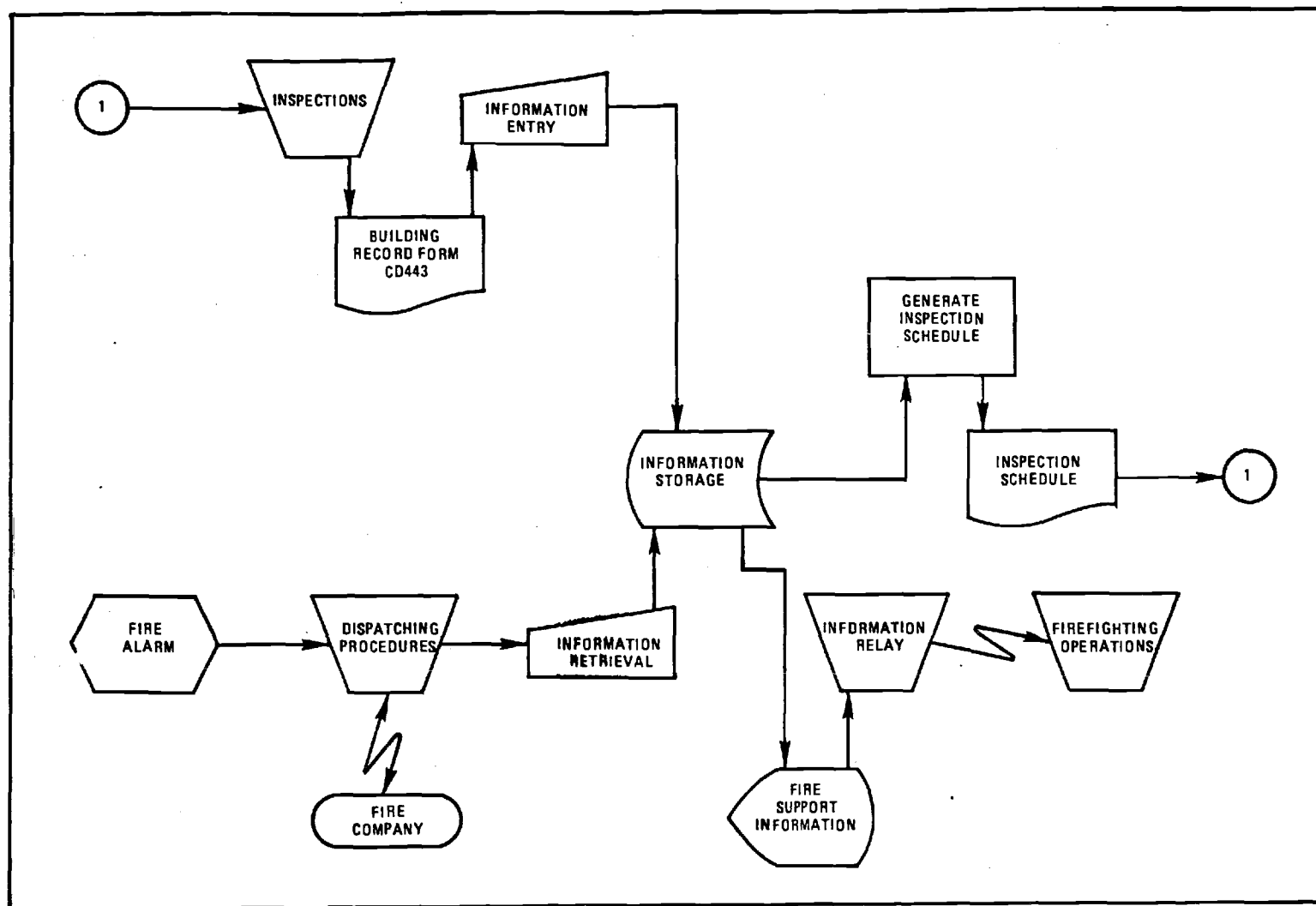


FIGURE 4-1. CHARLOTTE FIRE OPERATION MODULE

(Source: "The Charlotte Integrated Municipal Information System Project, Fire Operations Module Design Specifications." [4-58])



ADDRESS:	NUMBER	UI	STREET NAME						TYP	BLDG.	FPB <input type="checkbox"/>					DATE / /	
												OPR <input type="checkbox"/>					

CHARLOTTE FIRE DEPARTMENT

[illegible]

(Source: "The Charlotte Integrated Municipal Information System Project, Fire Operations Module Design Specifications." [4-58])

operating in the California communities of Berkeley, Fresno, Mountain View, Oakland, Palo Alto, Sacramento, and San Jose. Gomberg [4-26] states that:

UFIRS is a system that uses up to five input reports to collect information on incident response from fire alarm headquarters, information on specific incidents from the responding officer in charge, information on equipment use from the company officer, information on fire investigations from the investigator, and casualty information in a keypunchable coding format based on NFPA No. 901. The collected data are then processed, classified, collated, and used to develop output reports designed to assist fire departments in monitoring their environment and their performance by taking advantage of computers to provide a high degree of data accessibility. The uniformity of the data base permits comparisons of data between jurisdictions and facilitates development of a large-scale data base.

Gomberg also points out that the value of UFIRS, or any other information system, depends upon effective use of the output reports. Management use of UFIRS output has been a major concern of the NFPA, and UFIRS Management-by-Data Workshops are conducted by the NFPA to assist users in the development of usage techniques.

The Pinnell-Anderson-Wilshire project [A-64, 4-53, 4-54] at Wichita Falls was completed in 1972. This project, under the direction of Col. Paul M. Yeager, Director of Public Safety, was initiated early in 1969. Its purpose was to investigate the application of systems management techniques to fire protection operations. The study was conducted in three phases, as follows:

- Analysis of existing fire protection operations and development of a computerized data processing system.
- Development of a simulation model for use in a comprehensive evaluation of the total system of fire protection.
- Systematic analysis and development of recommendations for more economical and efficient management.

Volume I of the Wichita Falls report describes the computer-based data system and fire inspection system.

The objectives of the data system were to (1) provide a computerized data collection and reporting system, (2) provide all pertinent operational data for subsequent analysis, (3) provide periodic operational reports

suitable for informed management decisions, and (4) provide a daily record of all alarm occurrences and all alarm dispatch activity.

Our Professionals Panel agreed that good solutions to problems involved in the design of management information systems are very important. All of the chiefs on the panel were involved with such systems and expected increased usage in the future. Comparative evaluation of computer-based management informative systems is virtually impossible. Each has been designed for the perceived needs of a specific municipality (even the UFIRS system was modified by each city using it). The effectiveness of the system, as NFPA points out, depends not only on what output, but also on what use is made of the output. A fire department which is interested in installing a computer-based system, however, should be aware of the advantages of an integrated system, such as developed for Charlotte and Long Beach, and should consider the advantages of the uniform reporting system developed by the NFPA.

#### 4.2 FIRE REPORTING SYSTEMS

Equipment and technical aspects of fire reporting systems are not within the defined scope of this project. However, research and related publications concerning design and effectiveness of fire reporting systems may have policy utility to fire protection service management. Such reports are the subject of this section.

The usual communications systems by which fire departments are notified that their services are needed are: (1) telegraph-type street boxes, (2) telephone-type street boxes, and (3) public telephones. According to Municipal Fire Administration, street fire alarm box systems are used in three of five communities of more than 5000 population. These systems have the advantage that the box location is transmitted automatically. The major disadvantage of the telegraph system is that only the location is transmitted. The fire department must respond without benefit of any knowledge concerning the nature of the emergency. Further, the telegraph system is particularly susceptible to malicious false alarms.

The public telephone is generally the most available and most widely used means for notifying the fire department of a fire. However, it too has disadvantages. Unlike fire alarm systems which transmit location automatically, use of the public telephone requires that this information be

obtained from the caller. Firemen in the control center sometimes have difficulty communicating with an excited caller. Further, there is the risk that an accident, serious storm, or overload usage could shut down the service when it is most needed. For these reasons, the ISO Grading Schedule, which allocates 550 points to alarm systems, concentrates on street box systems and treats commercial telephones as a valuable auxiliary service.

All three of the above reporting procedures require that someone actually observe the fire and initiate an alarm. Thus, there is a "built in" delay of perhaps several minutes before the fire department learns of the blaze. All of the work on fire spread indicates that these minutes are crucial in terms of life and property loss.<sup>1</sup> For this reason, there is an increasing interest in fire detection systems which automatically and quickly detect a fire, warn occupants, and notify the fire department. Doctor, Levenson and Tenzer, in 1971, conducted a study of the feasibility of using such early detection and warning systems (EDWS) in New York City [4-19]. The concept which they investigated is shown in Figure 4-3. Their study concentrated on the following:

- Determination of the physical form that the system might take
- Assessment of technological feasibility
- Estimation of costs and benefits that could result from implementation of the system

As a result of the study, the authors concluded that an early detection and warning system was technically feasible. They further stated that:

An unequivocal statement of economic feasibility cannot be made at this time because we lack information on the nature and magnitude of fire losses in the city. We find, however, that the potential benefits of an EDWS are so large that further consideration of its application in New York City is recommended.

The study is well done and is recommended to any one interested in early detection and warning systems.

The only other study dealing with fire reporting systems is an investigation by Lingenfelter [A-35] of telephone and telegraph-type

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1. Fire growth with time is discussed in Section 5.1.1.

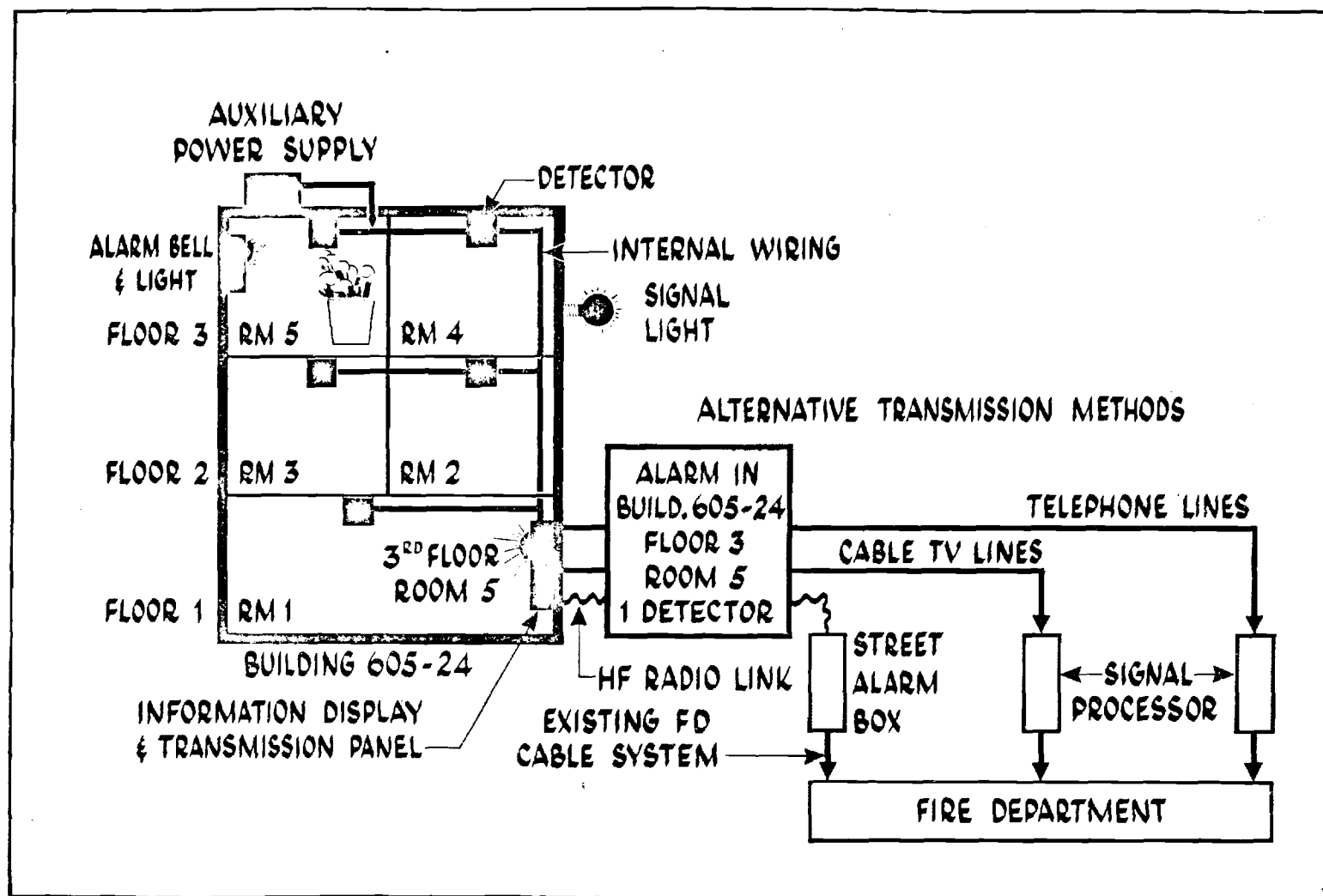


FIGURE 4-3. EARLY FIRE DETECTION AND WARNING SYSTEM

(Source: Doctor, Levenson and Tenzer [4-19]).

alarm systems with respect to malicious false alarms. This study, conducted in 1966, used a questionnaire to obtain information concerning type of alarm system frequency of alarms, and malicious alarms in 90 cities of 40,000 to 500,000 population. The objective of the study was to test the hypothesis that malicious false alarms in selected municipalities could be lessened by replacing the telegraph-type alarm system with the telephone-type system.

Results of the survey indicated that the frequency of malicious false alarms is significantly less for telephone-type systems. In fact, a ratio of approximately two to one was noted for various statistics describing the occurrence of malicious false alarms for the telegraph system compared with the telephone system.

The results of the survey are consistent with experiences of the chiefs on the Professionals Panel. They pointed out that the present trend is to use the public telephone system for fire alarm. Also, the use of an easily memorized number for all emergency service calls is increasing rapidly.

Most of the experience reports dealing with alarm systems were published in the period from 1955-1962 and were concerned with the use of telephones for alarm systems. These are referenced at the end of this chapter.

The matter of fire reporting systems has not received much attention from researchers. Types of systems now in use were established many years ago and continue in use through tradition and lack of successful economic challenge. The study by Doctor, Levenson and Tenzer is a good first step toward better fire reporting. They define a set of discrete intervals for the time between the start of a fire and the beginning of extinguishing operations, the first two of which are:

- time from fire start to detection
- time from detection to notification of fire department dispatcher

It seems clear that, in order to justify improvements in fire detection and reporting, we must know more about the losses which occur during these two periods.

#### 4.3 DISPATCH/CONTROL SYSTEMS

There is general agreement among researchers and practitioners that

the elapsed time between receipt of an alarm and arrival of fire equipment on the scene is a vital factor in successful fire extinguishment.<sup>1</sup> A portion of this time is taken up by the control center in processing the alarm, as follows:

- Receive alarm
- Record pertinent information
- Determine the exact location
- Determine what apparatus is needed
- Determine what apparatus is available
- Determine what apparatus to dispatch
- Dispatch apparatus

In addition to these dispatch activities, the control center serves as a data location point, assesses coverage and relocated apparatus, keeps up to date on the status of all apparatus, and communicates needed information to officers at the fire scene.

The procedure for dispatching appears to be similar in most fire departments. When an alarm is received and the location determined, dispatchers consult a "running" card to see which units should be dispatched. This card contains information concerning how many units to send in response to the first and succeeding alarms. In some cities, it also lists preplanned relocations to cover areas from which apparatus has been withdrawn. The card implicitly assumes that no other fire is in progress at the time. If this is not true, the dispatch must know which of the units are committed and where to find their replacements. Thus, in large cities at least, the dispatcher is forced to make rapid deployment decisions.

Swersey [A-55, A-56], studied the alarm processing procedure in New York City in 1969. The model which he assumed for the dispatching process consists of three stages: (1) alarm receipt up to and including locating the alarm assignment card, (2) the decision process, and (3) actual transmission to units. Swersey stated that the third stage is fairly constant, and therefore, it was assumed that an alarm was not delayed at that stage.

After collecting considerable data, Swersey developed a simulation model to determine how dispatching time varies with different alarm rates

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1. Response time as a criterion for fire suppression resource allocation is discussed in Section 5.1.

and different communications office manning schedules. Simulation results indicated that the expected dispatching time increased relatively slowly up to a rate of about 25 alarms per hour. For further increases in the alarm rate, the expected dispatching time increased sharply--about nine minutes at 35 alarms per hour. The cause was found to be at the second stage of the process, the decision-making point. Under the procedure in use at that time, decisions were made by a single decision maker. As the alarm rate increased and equipment became increasingly unavailable, the time required for the dispatching decision became increasingly longer.

Improvement recommendations made by Swersey centered on two alternatives: (1) facilitate the decision process or (2) increase the number of decision makers. He suggested several ways to facilitate the decision process: (1) provide more current status information and update this information faster, (2) improve radio system capacity, and (3) improve the physical layout of the communications office. He further suggested that the borough be divided into two parts, with a separate decision maker responsible for the alarms and units in each half. Further simulations using two decision makers indicated that up to 43 alarms per hour could be processed with no appreciable delays.

Swersey's report makes no claims for general applicability of the results inasmuch as it was specifically conducted for New York City. It appears to be, however, a good example of the type of analysis which many large city fire departments might find useful. Swersey's work is the only effort to study the nature of the dispatching process.

The advent of computer usage in dispatcher/control systems is evidenced by the number of information systems design reports, advocacy papers, and experience reports which have been published in the last decade. Shanesy [4-42] has prepared a users manual for an on-line relocation program for the New York City Fire Department.<sup>1</sup> This computerized procedure allows a dispatcher to monitor protection in a specified area on a real-time basis. He enters apparatus status changes into the system through a terminal in the control center. The computer processes this information and warns the dispatcher when commitments to ongoing fires

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1. See Section 6.3 for a discussion of repositioning policies.



have stripped certain areas of fire protection. Further, it suggests how to reposition units most effectively to correct the situation.

Nielsen and Ryland [4-36], in 1968, reported the preliminary design of a computer-based command-control system for the Los Angeles City Fire Department by ARINC Research Corporation. The general requirement which guided the design was that any dispatcher must be able to handle incidents of any type or any magnitude at any console position. Each console was to have fire alarm box readout, incoming public telephone trunk lines, direct telephone links to other emergency agencies, communications links to all fire stations, radio links for all fire department frequencies, rapid access to the street index, detailed maps and emergency procedures, the location and status information on all LAFD units, information concerning incidents being handled at other console positions, and communication links to other console positions. The specific functional requirements were that the system should:

- keep track of the status of various LAFD units,
- maintain unit status information without attention from dispatch personnel,
- identify rapidly the appropriate available assignment for each incident handled by LAFD,
- automatically establish communications links, including land-line voice, radio voice, and teletype, to dispatch units,
- automatically maintain the status of each active incident and display it to dispatch and command personnel as requested, and
- maintain, identify rapidly, and display as needed, detailed street maps, utility distribution maps, and emergency procedures.

According to the Nielsen - Ryland report, unit status information was to be displayed primarily on the console CRT displays. Automatically or on dispatcher demand, the system was to identify and display the appropriate assignment for a specific incident, with proper consideration of type of incident, severity and location.

Since the system seemed to be out-standing, and no reports of implementation could be located, a telephone call was made to the Los Angeles City Fire Department. According to Chief Adams, implementation of the system

was started on October 2, 1974 under the direction of the PSSI Corp. of Santa Barbara.

Adler [4-1], in June 1973 , advocated a computer based command and control system with the following four functions:

- A computer aided dispatch system using vidio display.
- An apparatus status system for fast and reliable data transmission from apparatus to the control center through the use of digital signaling techniques.
- A data management system for storage and retrieval of various types of information.
- A printer communications system to enable a dispatcher to transmit radio messages to remote apparatus which are then transformed into permanent hard copy.

According to a note published with Adler's paper, New Orleans was one of the cities implementing the command and control system.

Another function of the dispatch/control system is that of providing information to fire fighting units (in transit or at the fire scene) to assist them in the task of extinguishment. The Charlotte Fire Operations Module [4-58]<sup>1</sup> draws upon information contained in the "Building Record." Operation of the system is described by the Charlotte Fire Department as follows:

Once the address of an alarm is provided by either a caller or the first company at the scene, the dispatcher retrieves fire support information by entering a transaction code and the address of concern on the VDT. No password is required in this instance since the information subsequently displayed cannot be altered in any manner.

Once the fire support information has been retrieved, the dispatcher initially compares the primary and secondary hydrant information displayed with out-of-service hydrant information supplied by the water department. The dispatcher relays this data, if applicable, along with the displayed fire support information to the responding firemen.

If the display provides a reference to a Slectroslide or document (map, book, manual), the information is manually retrieved for subsequent relay to company personnel at the

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1. See Section 4.2 for discussion of the Charlotte Integrated Municipal Information Systems Project.

scene of the alarm. Information contained within the designated reference sources may include fire attack plans, pre-fire planning data, chemical properties, or geographical information.

If the senior officer at the scene determines that a nearby building (exposure) is endangered, the address of the exposure need only be provided to the dispatcher to retrieve fire support information for the building in question.

Information relating to building ownership, the conduct of inspections, and incidents (if any) for a given building is also retrieved and displayed in a manner consistent with that indicated for fire support data.

The preceding discussions are not offered as an exhaustive state-of-the-art report on computer-based dispatch/control systems. Since published literature usually lags real-time events by several months, it is likely that systems other than those discussed are now in operation. It seems safe to conclude, however, that there is a great deal of activity in the area of computer-based dispatch/control systems in large and medium-sized cities. Moreover, rapid advances in computer technology and the general availability of computers indicate that the advantages of such systems soon may be available to smaller cities as well.

So far, there is a lack of empirical studies to guide the design of computerized dispatch/control systems. Only Swersey has studied the dispatching process and his work was specifically related to a borough of New York. As computer-based systems become operative, it is likely that studies of their operation will be needed in order to increase their effectiveness and reduce costs.

#### 4.4 FIRE COMMUNICATIONS SYSTEMS

In many fire departments, fire communications includes alarm systems. For purpose of this discussion, however, fire communications systems include only the following:

- Communication systems for call-out, and
- Systems for communication among units at a fire scene and between such units and the control center.

Much of the published material concerning these subjects is technical

and "hardware-oriented." As such, it is not appropriate for discussion here.

Apparently, no policy-related research concerning communication systems has been conducted. However, there are several experience reports which may be of interest to fire service professionals. Articles concerning call-out systems and fire scene communications are referenced at the end of this chapter.

The lack of research on fire communications systems seems to be consistent with the views of the Professionals Panel, which felt that this was not a high priority area.

#### 4.5 CONTROL OF TRAFFIC SIGNAL SYSTEMS

Fire protection service managers have always been concerned with quick and timely response to alarms and in the safety of both firemen and the public during the emergency run. All municipalities have laws requiring nonemergency vehicles to give right-of-way to emergency vehicles on emergency runs. However, drivers must stop at signal-controlled intersections when the light is red and the resulting road block prevents passage of the emergency vehicle.

Over the years, a number of schemes for controlling traffic signals so as to give emergency vehicles a "green light" have been tested. Those which have been reported fall into one of the following types:

- Driver control
- Automatic control from the vehicle
- Computer control from a central headquarters

Reports describing these systems invariably concentrate on how the system operates, but offer no quantitative appraisal of cost-effectiveness or measures of effectiveness. It is not possible, therefore, to compare different systems or to compare any one system with the noncontrolled situation.

The first report of a driver-controlled system [4-65] was published in 1956 and describes a radio control for traffic signals and cites applications in Maywood, Illinois and New Haven, Connecticut. Two systems for automatic control by the moving emergency vehicle have been reported in recent years. The first, in 1969, [4-54] describes the Tuscon, Arizona, system, which is called the Opticom (optical communications) emergency

corridor control. This system uses high-intensity flashing strobe light (similar to those used on airport runways) which triggers control mechanisms on traffic signals up to one-third mile ahead of the emergency vehicle. The flashing light also alerts oncoming traffic even more effectively than the customary red warning light. (It does not replace the warning light, however.) A second emergency vehicle coming from a 90° direction cannot override the green light if it has been triggered. Thus, drivers know to stop if the light does not turn green in response to the signal from their vehicle.

A second system, described in 1972, utilizes wire loops placed under the street in advance of the traffic signal and a low-frequency transmitter on the vehicle. This system has been tested in the City of Bath, England. The only known computer-controlled system is also in England. Taking advantage of their computer-controlled traffic signal systems, the City of Liverpool has installed the "Green Wave" system [4-29, 4-46]. On the receipt of a fire call, brigade control initiates a demand on the control computer, which, in turn, transmits control signals to the groups of intersections to form a "green wave" flow along a preselected route. Drivers of fire apparatus either know the route or are instructed by radio.

#### 4.6 SUMMARY

Some of the most exciting innovations in the fire protection service are those involving information and communications systems. For the most part, these improvements are clearly the result of space-age communications and computer technology. Impetus for adaptation of this technology to urban management, including the fire protecting service, has been provided by federal agencies, particularly the Department of Housing and Urban Development. As a result of these efforts, computer-based information and control systems are now operating in Charlotte, Long Beach, Wichita Falls, Los Angeles, and other cities. Each of these provides a case study of great potential value to those fire departments which design and implement such systems in the future. The next logical step in the evolutionary development and use of computer-based information and control systems is the analysis of effective use of the capability which these systems provide.

The NFPA has already started this activity for cities using the Uniform Fire Incident Reporting System through a series of seminars and workshops devoted to "Fire Department Management Problem Solving Techniques Using UFIRS Data."

In the specific area of alarm systems, an effort to make general use of advanced technology has only just begun. For the most part, the present systems represent large investments and major changes would be very costly. There is a clear and unmistakable need for studies to determine the economic feasibility of various types of alarm systems. So far, the missing component for such studies is knowledge concerning fire losses which result from delays in fire detection and reporting. Until someone sheds light on this matter, progress is likely to be stymied.

The situation regarding control of traffic signals to speed fire apparatus through crowded streets is much the same as that for fire reporting systems. Technology is available and technical feasibility is established. Economic feasibility must await better data concerning the benefits of these systems.

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## CHAPTER 5

### CRITERIA FOR SUPPRESSION RESOURCE ALLOCATION

By far the greatest part of direct expenditures for fire protection is allocated to fire suppression. Thus, it is not surprising that the largest and most coherent body of research reviewed for this report concerns fire suppression resource allocation, i.e., the positioning, repositioning, and assignment to fires of suppression forces and equipment.

For purposes of this report the issue of fire suppression resource allocation has been divided into two separate questions. Section 3.3 addressed the first of these, "What is the proper composition of fire companies?" The present and following chapters will focus on the second, "How should fire companies be allocated?" It is obvious that a complete policy for allocation of suppression resources involves related decisions on both these questions. For example, a fire department with two-man companies could be expected to have much different dispatching rules from one with five-man companies. However, all known research has addressed the two allocation issues separately, and that convention is also adopted in this report.

Like any resource allocation problem, the question of the best positioning, repositioning, and assignment to calls of fire suppression companies also can be divided into two parts. The limitations on the range of alternative allocations which derive from budget limitations, street patterns, political boundaries, etc., constitute the constraints of the problem. For example, the decision on location of a new fire station may be restricted by the availability of suitable parcels of real estate.

To choose among the alternative allocations which can satisfy the problem constraints, the second component of an allocation problem--a criterion or objective function--is required. For example, the decision on the best of the possible locations for a new fire station might be

based on minimizing average response time of the first-arriving company to fires in the area of a new station.

As with the questions of company manning and company allocations, the constraints and objective functions for company allocation problems are closely related. However, to make possible a more thorough comparison of results from different researchers, the questions are separated in this report. The current chapter addresses research on criteria for allocation of fire companies, while the following one deals with the constraints and solution of particular allocation problems.

Research on the development of criteria for choosing among positioning, repositioning, and dispatching plans for fire suppression companies involves two separate steps. First, criteria for the adequacy of a plan in protecting individual areas of structures must be developed. The most studied of these measures of protection for individual risks is the response time of suppression forces. To collect the criteria values for individual risks into an overall measure of the value of a proposed allocation plan, the second step of criteria development is employed. Criteria values for individual risks are averaged into composite or overall criteria.

The following sections address both steps. Attention is first turned to evaluation for individual risks, with special study of the response time and fire demand measures which have been most completely developed in the fire research literature. A final section then deals with aggregation of the individual values.

## 5.1 RESPONSE TIME

It seems generally agreed among fire researchers that the ideal measure of the effect of a suppression allocation plan on a particular neighborhood would be the reduction in loss of life and property resulting from the plan. However, it seems just as generally agreed that estimation of such losses is hopelessly difficult, at least prior to implementation of the plan.

Thus, many researchers have turned to surrogate or proxy measures which are more easily quantified and closely related to fire losses.

By far the most commonly proposed such proxy criterion for allocation of fire suppression resources is response time, i.e., the time between the report of a fire and the arrival on the scene of fire suppression forces.

The popularity of this criterion has derived from the four important assumptions that:

- (1) Fire property losses and injuries increase as the time from ignition of the fire to arrival of suppression forces increases.
- (2) The resources required to control a fire increase as the time from ignition to arrival of suppression forces increases.
- (3) Response time is more easily measured and studied than fire losses.
- (4) Response time is a significant part of the time from fire ignition to arrival of suppression forces (often referred to as pre-burn time).

To the extent that these assumptions can be empirically justified, response time is a valid and useful criterion.

The validity of the first three of these assumptions has been at least partially researched. The status of this research is summarized in the following subsections.

The vital assumption that response time is a significant part of pre-burn time apparently has not been as carefully studied. The Professionals Panel did find the assumption consistent with their experience. However, the question appears worthy of research because a finding that a majority of pre-burn time occurs before a fire is reported would suggest a significant reallocation of fire protection resources. Much more attention would need to be directed to fire detection.

#### 5.1.1 FIRE GROWTH WITH TIME

The total loss associated with a fire includes property damage, personal injuries and deaths, smoke damage, and many other elements. The most important argument offered for the use of response time as a criterion for allocation of fire suppression resources is that these

fire losses tend to grow with time, i.e., that response time is an adequate surrogate measure of the total loss associated with a fire.

Though it is nearly self-evident that the size of a fire and the associated loss will tend to increase with pre-burn time, the pattern of this growth is not well understood. For example, if most fires tend to remain in a minor state for a fairly long time, and only expand to major proportions if truly ignored, then time would be relatively unimportant to fire loss. If, on the other hand, fires tended to reach a dangerous size at about the same time they are reported, then response time would become a very important element in reducing fire losses.

The growth and spread of uncontrolled fires has been the subject of laboratory research and mathematical modeling in fire engineering for a number of years. However, that research is beyond the scope of this report, and no attempt will be made to collect such work or to synthesize the findings.

The one set of careful research on the growth of fires with time which did fall within the scope of this report is the work of Hogg [A-20]. In her studies reports of fires in the United Kingdom during 1963 and 1967 were analyzed to identify the ultimate extent of the fire, the point of origin of the fire, and the occurrence of fatalities at the fire. These various measures of fire loss were associated with the observed response time of the fire brigades to determine the effect of time on loss.

In a first analysis fires were divided into three stages of growth. Stage 1 was the period when the fire was contained to its room of origin; Stage 2 was the period during which the fire had spread beyond its room of origin but remained on the same floor; and Stage 3 was the period after the fire had spread to a different floor of the building. The proportion of fires which had advanced to each of these stages was then associated with the response time of the fire brigades.

Tables 5-1 and 5-2 show the results of this analysis for dwellings, and industrial and commercial premises, respectively. The results clearly indicate a tendency for fires to be found in more advanced



TABLE 5-1. DWELLING FIRES OBSERVED BY FIRE STAGE REACHED AND RESPONSE TIME

Time between discovery and arrival of FB t	Proportion of fires at time t			Observed frequency of fires at time t
	Confined to room	Spread beyond room but confined to floor	Spread beyond floor	
	Observed	Observed	Observed	
(1)				
2	.842	.088	.070	57
3	.801	.079	.120	316
4	.793	.089	.118	1212
5	.780	.096	.124	2092
6	.768	.093	.139	2209
7	.771	.094	.136	1665
8	.783	.078	.139	1186
9	.736	.083	.182	749
10	.733	.102	.165	570
11	.744	.091	.165	328
12	.730	.073	.197	274
13	.739	.085	.176	176
14	.702	.083	.215	121
15	.638	.079	.283	127
16	.570	.038	.392	79
17	.684	.053	.263	57
18	.533	.117	.350	60
19	.636	.000	.364	33
20	.507	.090	.403	67
(1)				
21	.515	.056	.429	231
1. All fires with a discovery to arrival time less than two minutes or greater than twenty-one minutes have been treated as if the time was two minutes or twenty-one minutes, respectively.				

(Source: Hogg [5-10])

TABLE 5-2. INDUSTRIAL AND COMMERCIAL PREMISE FIRES  
OBSERVED BY FIRE STAGE AND RESPONSE TIME

Proportion of fires at time t				
Time between discovery and arrival of FB t	Confined to room	Spread beyond room but confined to floor	Spread beyond floor	Observed frequency of fires at time t
	Observed	Observed	Observed	
(1)				
2	.761	.080	.159	113
3	.676	.074	.250	380
4	.656	.083	.261	1000
5	.648	.084	.268	1393
6	.641	.079	.280	1156
7	.620	.082	.298	782
8	.628	.081	.291	508
9	.616	.081	.303	271
10	.603	.095	.302	199
11	.504	.115	.381	113
12	.549	.077	.374	91
13	.438	.078	.484	64
14	.511	.064	.426	47
15	.364	.159	.477	44
(1)				
16	.479	.069	.452	217
1. All fires with a discovery to arrival time of less than two minutes or greater than sixteen minutes have been treated as if the time was two minutes or sixteen minutes, respectively.				

(Source: Hogg [5-10])

stages when response times are longer. Thus, the analysis suggests the loss associated with a fire would be correspondingly greater when response time is longer.

A similar approach was used by Hogg to analyze the effect of response time on fatalities. Using the 1963 and 1967 data, the proportion of fires which involved at least one fatality was determined for various fire brigade response times.

Results of this analysis are given in Table 5-3. The proportion of fires with fatalities clearly tends to increase as response time increases.

Though more complete reviews of the fire spread literature would be required to reach firm conclusions, these two analyses certainly tend to support the assumption that fire losses grow with response time. Moreover, the Professionals Panel confirmed that such an assumption was consistent with their experience.

#### 5.1.2 RESOURCE REQUIREMENT GROWTH WITH TIME

The second argument often advanced for the use of response time as a criterion is that the suppression resources required to control a fire also grow with the time between ignition and arrival of fire suppression forces, i.e., with pre-burn time. If true, this suggestion implies a significant interaction between response times and suppression resource allocations. Improved response times may not only reduce the size of fire loss, but also reduce the size of the suppression force required to protect a given jurisdiction.

The Professionals Panel found the assumption that suppression resource requirements grow with pre-burn time consistent with their professional experience. However, no empirical research was identified which directly analyzed such a relationship.

The most closely related research identified for this report is the work of Labes [A-30, A-31], Salzberg [A-50], and others at the Illinois Institute of Technology Research Institute. In the main part of these studies, 63 residential and 64 nonresidential fires in the Chicago area were very carefully investigated by the research team. The maximum area of each fire was recorded, along with the time the

TABLE 5-3. FIRES WITH FATALITIES BY RESPONSE TIME

Time between discovery and arrival of FB t	Proportion of fires at time t which were actually fatal <hr/> Observed	Observed frequency of fires at time t
(1)		
2	.143	7
3	.150	40
4	.155	207
5	.155	362
6	.195	411
7	.145	262
8	.162	228
9	.190	158
10	.183	120
11	.205	78
12	.250	64
13	.119	42
14	.265	34
15	.366	41
16	.250	12
17	.458	24
18	.417	24
19	.400	15
20	.273	22
(1)		
21	.331	281
1. All fires with a discovery to arrival time less than two minutes or greater than twenty-one minutes have been treated as if the time was two minutes or twenty-one minutes, respectively.		

(Source: Hogg [5-10])

fire was judged under control by the commanding officer at the scene, and the arrival and departure times of all suppression forces and equipment committed to the fire. Information on the committed suppression forces and equipment was then used to estimate the total volume of water applied to the fire, the maximum water application rate, and the man-hours of firemen's time committed to the fire.

Statistical regression of each measure of fire suppression resources on the maximum area of the fire produced the graphs of Figure 5-1. The relationships depicted in the graphs show that the time to control the fire, the quantity of water applied, the maximum application rate of water, and the man-hours committed to fires all tended to increase with the maximum fire area. No numerical information was provided by the authors on the statistical accuracy of these relationships, but the graphs appear to show sufficient accuracy to at least confirm the tendency of all resources to increase with fire area.

To assure that the above results were not caused by special characteristics of the Chicago area, a limited study was made of fires in four other cities--Los Angeles and Buena Park, California; and New York City and White Plains, New York. While sample sizes in these latter studies were too small to make definitive conclusions, the results generally tended to support the Chicago work.

Under the assumption that maximum fire area tends to increase with pre-burn time, these results provide significant empirical evidence that fire suppression resources required to fight fires also increase with pre-burn time. Moreover, the Professionals Panel found such conclusions appropriate to their understanding of the environment in many cities.

### 5.1.3 ESTIMATION OF RESPONSE TIMES

The third important assumption on which the usefulness of response time as a criterion rests is that response time can be easily and accurately estimated for a given allocation plan. Once an allocation of fire suppression companies has been established, response times of the various companies can be measured directly. It is only necessary to record the time alarms are received and the times various companies

# RESIDENTIAL FIRES

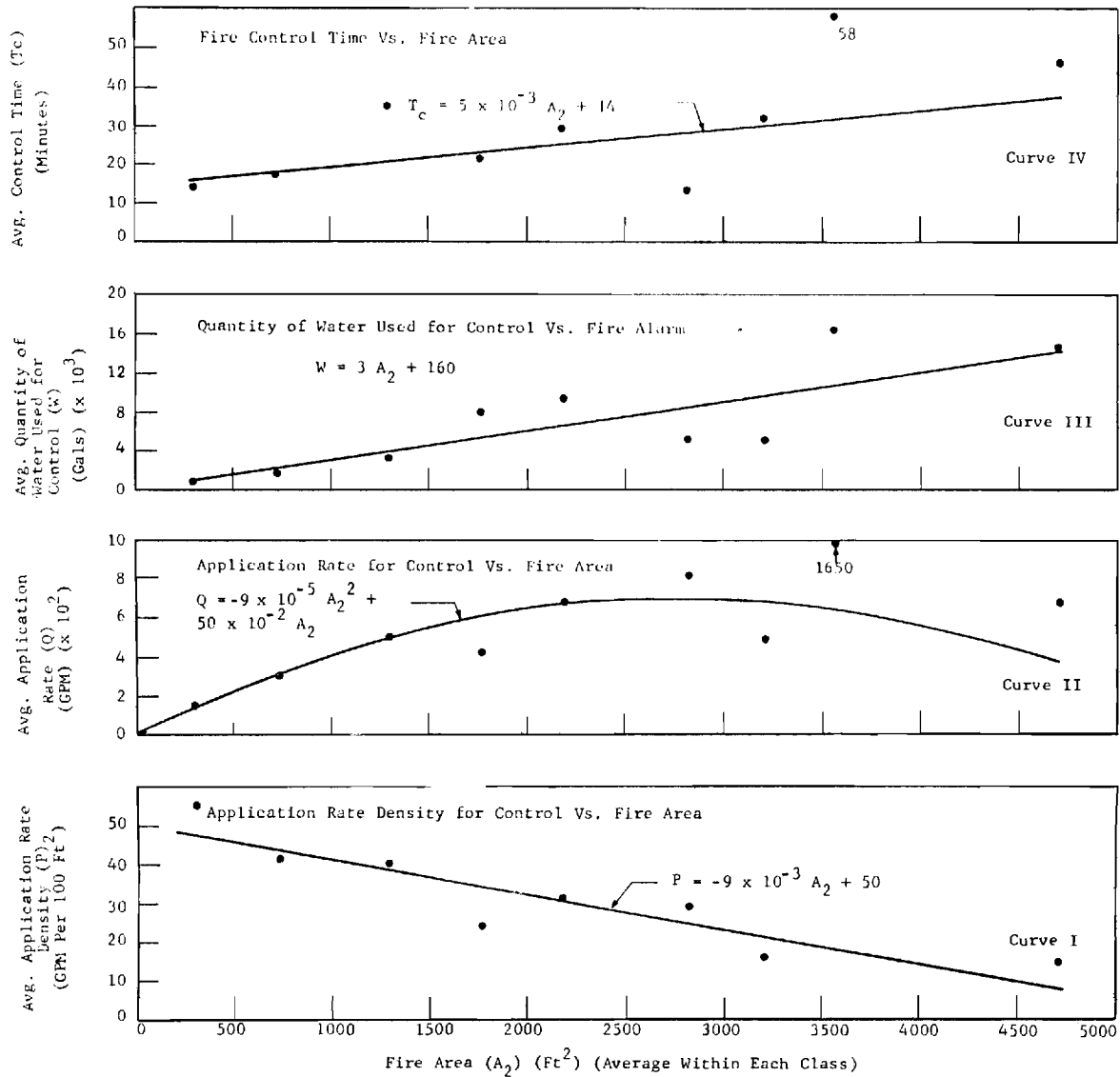


FIGURE 5-1. GROWTH OF SUPPRESSION RESOURCE REQUIREMENTS WITH MAXIMUM FIRE AREA

# NON RESIDENTIAL FIRES

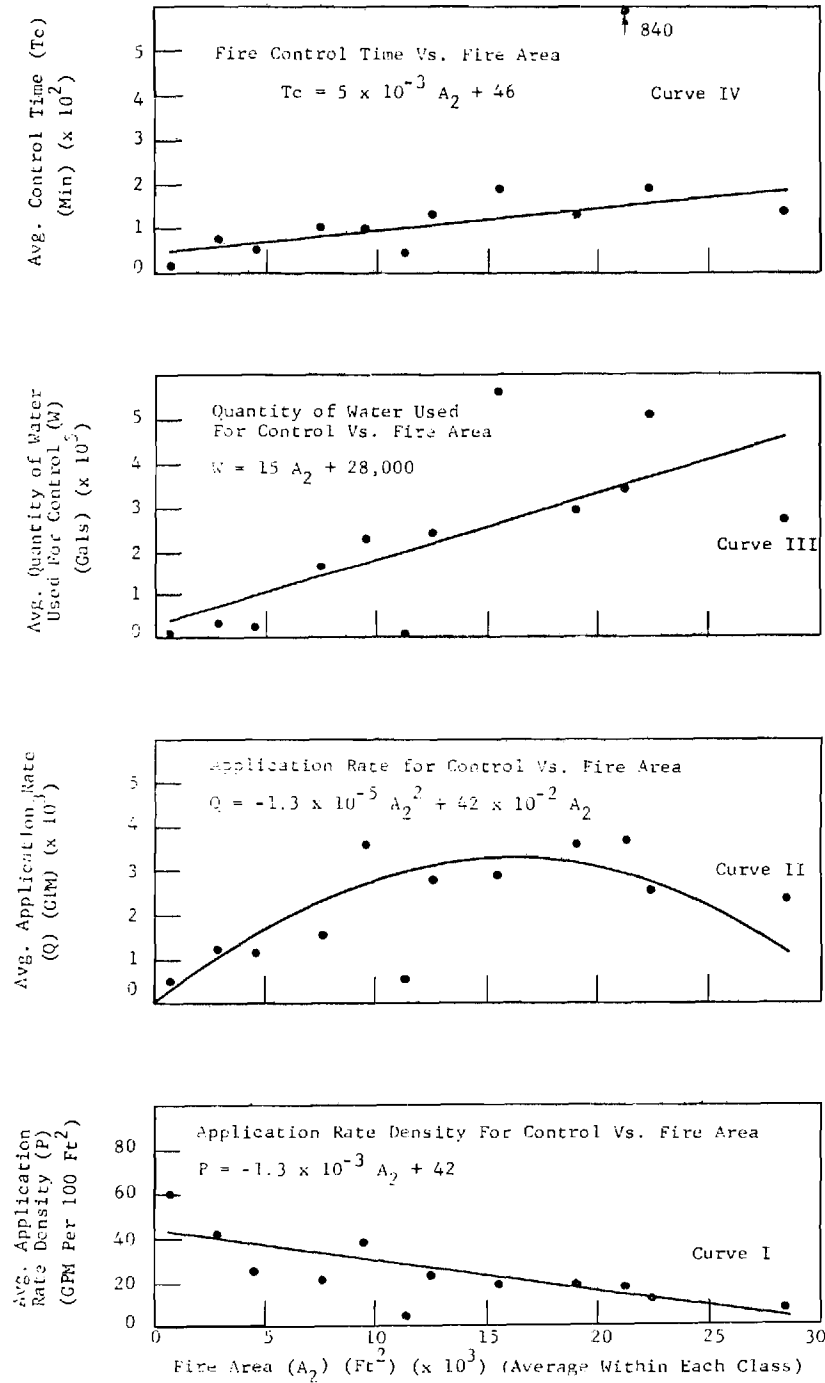
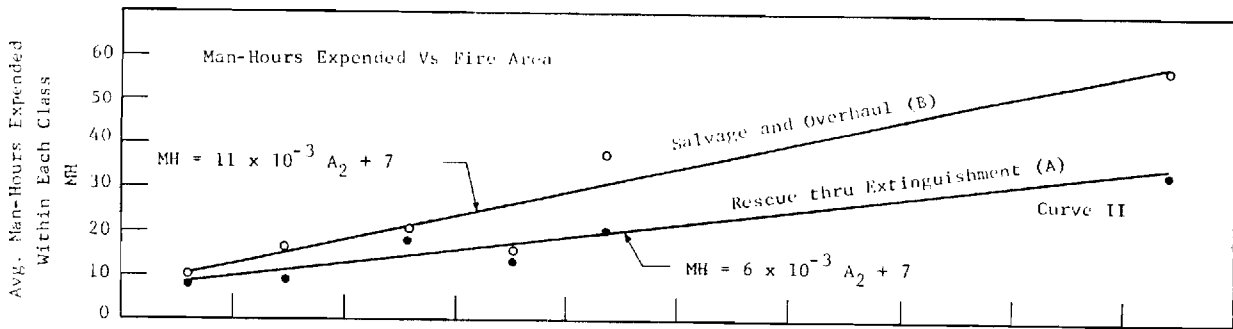


FIGURE 5-1. (CONTINUED)

# RESIDENTIAL FIRES



# NON RESIDENTIAL FIRES

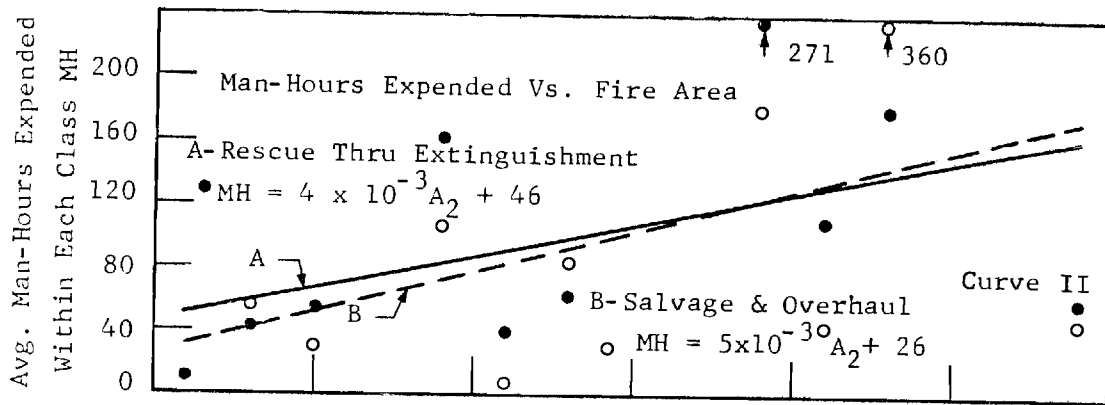


FIGURE 5-1. (CONTINUED)

(Source: Labes [A-31])



arrive on the fire scene.

However, in order to select among company allocations before they have been implemented, a procedure for estimating response times from the allocation plan is required. It must be possible to accurately approximate the response time behavior of a proposed allocation on the basis of the proposed company positioning, repositioning, and dispatching rules, and historic data about the times and locations of fires. Research on the estimation of response times focuses on the identification of such estimation procedures.

Nearly every study identified for this report which used response time as a criterion for allocation of suppression resources approached this estimation problem by assuming some relationship between time and distance. Distance is obtained by consideration of the geographic locations of hypothetical fires and the responding companies, and time is then estimated indirectly via calculations on distance.

The various studies employed several different measures of distance for this purpose. On occasion, available representations of the street network permitted using actual street mileage. More often, one of two less exact measures was employed. The first of these is straight-line or Euclidean distance, i.e., the straight-line path from the fire station to the fire scene. The second is rectilinear or block distance, i.e., the path from the fire station to the fire scene through a rectangular grid street pattern. Either of these approximate distances can be readily determined if the map coordinates of a fire station and fire scene are known.

Almost every study of suppression resource allocation using a distance-based procedure for estimating response time attempted some estimation of the parameters in the assumed time-to-distance relationship. However, significant empirical studies of the relation between various measures of time and distance were found in only four research studies reviewed for this report.

Hogg's [A-21] study of Glasgow, Scotland, involved a sample of response times to fires during 1966. The study began by mounting a recording device on one pumper unit during three months of 1966 to obtain an estimate of the proportion of response time spent leaving the

station as opposed to actually traveling. The 5 percent estimate obtained from this special analysis then was deducted from a city-wide sample of response times to obtain estimated travel times. These travel times, in turn, were combined with the actual travel distances of the responses to obtain the average travel speeds shown in Table 5-4. As indicated in that table, the average travel speed for all Glasgow was calculated in this manner at 16.2 miles per hour.

Mitchell's [A-39, A-40] analysis of travel time and distance relationships was based on 922 incidents recorded in Fullerton, California, during 1968. For each incident, the response time of the first responding company was obtained, along with the total recorded mileage of the fire run. Total mileage was divided in half to obtain an estimate of actual street mileage to the fire. Map coordinates of the fire station also were obtained so that both rectilinear and Euclidean distance could be estimated.

Analysis of these data showed an average response time of 4.01 minutes and average response distance of 1.66, 1.03, and 1.29 miles for the actual, Euclidean, and rectilinear distances, respectively. Thus, the results showed actual travel distance to be larger than either Euclidean or rectilinear distance. However, rectilinear distance appeared to be more accurate than Euclidean distance as an estimator of actual distance.

Application of linear regression to the above data produced the following relationships:

$$\text{Travel time} = 2.152 + 1.118 (\text{actual distance})$$

$$\text{Travel time} = 2.377 + 1.587 (\text{Euclidean distance})$$

$$\text{Travel time} = 2.328 + 1.302 (\text{rectilinear distance})$$

None of the relationships provided a highly reliable fit because times varied considerably at all levels of all distance measures. However, the quality of the fit was substantially the same for all measures of distance.<sup>1</sup>

---

1. Coefficients of correlation were 0.601, 0.565, and 0.568 for actual, Euclidean, and rectilinear distance, respectively.

TABLE 5-4. ESTIMATED RESPONSE SPEEDS IN GLASGOW

Year	Area of Glasgow	Type of Road	Mean Speed (mph)
1966	Knightswood Station Area	Non-motorway	23.1
"	Queen's Park Station Area	"	17.5
"	North West Station Area	"	11.9
"	Castlemilk Station Area	"	18.5
"	Parkhead Station Area	"	14.2
"	Pollok Station Area	"	25.5
"	Easterhouse Station Area	"	18.7
"	South Station Area	"	11.8
"	Partick Station Area	"	13.5
"	Govan Station Area	"	17.1
"	West Station Area	"	7.8
"	North Station Area	"	14.8
"	Central Station Area	"	12.6
"	Springburn Station Area	"	22.2
"	East Station Area	"	15.6
1966	Glasgow--All Station Areas	"	16.2

(Source: Hogg [A-21])

In an additional analysis, Mitchell tested whether the time-to-distance relationship changed by time of day in Fullerton. This analysis showed an average response time of 3.91 minutes for calls between 6 AM and 11 PM and an average response time of 4.63 for calls between 11 PM and 6 AM. Thus, response in the night hours was somewhat slower than during the daytime.

A third study of the relation between travel time and distance was performed by Pinnell-Anderson-Wilshire Associates in their study of Wichita Falls, Texas [A-64]. In this analysis, data were assembled on 1,434 in-city and 79 out-of-city alarms occurring during 1970. For the out-of-city alarms, both response times and response distances were readily available, but response distance had to be estimated for the in-city alarms. An estimate was obtained by measuring the travel distance from the closest fire station to the center of the fire zone in which the fire occurred.

The results of this analysis of Wichita Falls for in-city and out-of-city data, respectively, are shown in Figures 5-2 and 5-3. In both cases, the figures show the average travel speed associated with different travel distances as derived from the time and distance data described above. The results appear to indicate a relatively stable speed of 35 to 45 miles per hour for distances in excess of two miles, but substantially slower speeds for distances of less than two miles.

Like Mitchell, Pinnell-Anderson-Wilshire also studied differences in response time by time of day. However, the only variations in response speeds observed in Wichita Falls were slightly slower responses for trips of less than two and one-half miles in the midnight to 3 AM time period.

A final significant empirical study of the time-to-distance relation is the work of Kolesar and Walker [A-28] in New York City. Data on response time and actual response distance were carefully recorded on 1772 responses of 13 ladder companies chosen from throughout that city.

The principal interest of the study was to determine an appropriate mathematical relationship between response time and distance. Three different relationships were considered:

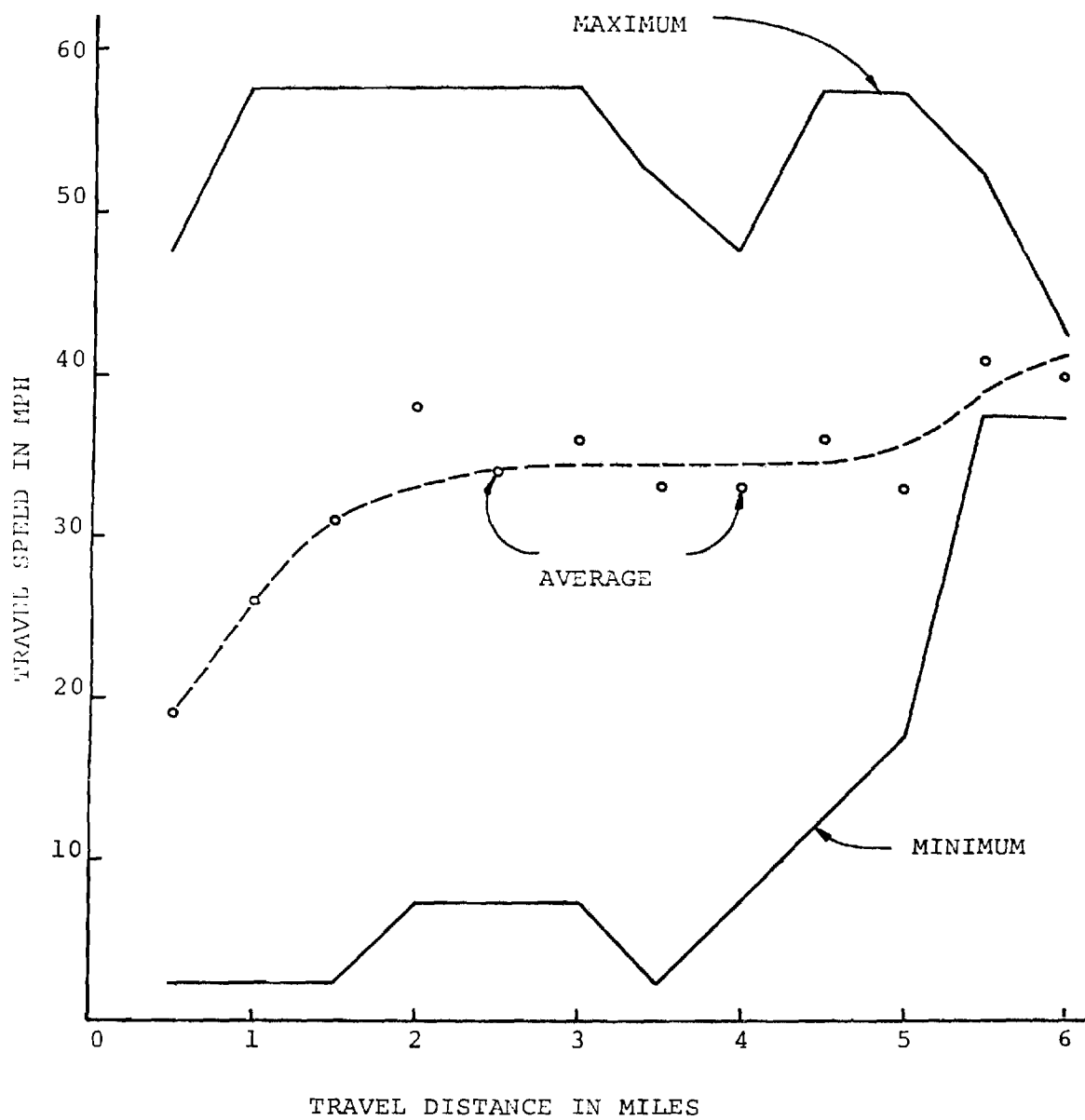


FIGURE 5-2. ESTIMATED RESPONSE SPEED FOR IN-CITY CALLS  
IN WICHITA FALLS, TEXAS

(Source: Pinnell-Anderson-Wilshire [A-64])

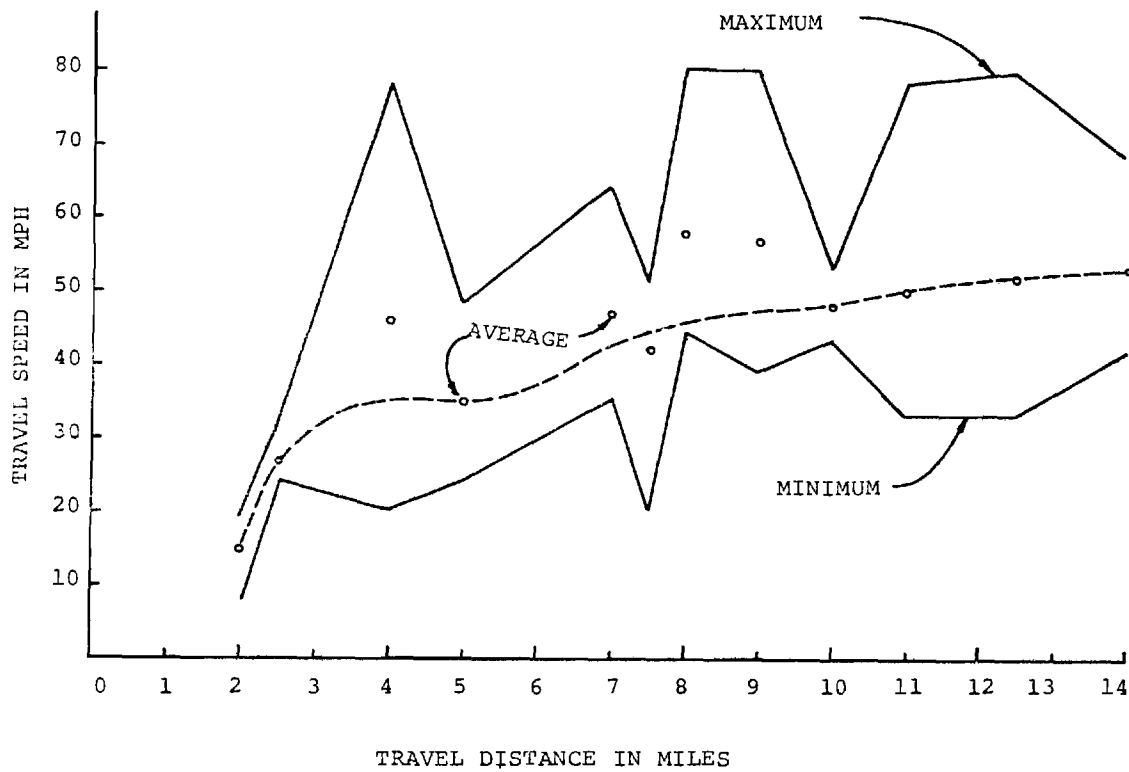


FIGURE 5-3. ESTIMATED RESPONSE SPEEDS FOR OUT-OF-CITY CALLS  
IN WICHITA FALLS, TEXAS

(Source: Pinnell-Anderson-Wilshire [A-64])

- (1)  $\text{Time} = \text{constant}_1 \sqrt{\text{distance}}$
- (2)  $\text{Time} = \text{constant}_1 + \text{constant}_2 (\text{distance})$
- (3)  $\text{Time} = \text{constant}_1 (\text{distance})^{\text{constant}_2}$

Each of the relationships was fitted by statistical regression to data for each of the ladder companies.

Though the statistical procedures used by the authors to compare results from these regressions are suspect, the conclusion reached is that the square root relationship, (1), provided a better fit for companies where response distances were short, while the linear relationship, (2), was superior for longer runs. Thus, the authors were led to consider a composite expression where the square root relationship applies for shorter runs and the linear relationship applies for longer runs. Direct fitting of such a relationship to the data from all ladder companies produced the expression

$$\text{Time} = \begin{cases} 3.05 \sqrt{\text{distance}} & \text{if distance} \leq 1.2 \text{ miles} \\ 1.67 + 1.39 (\text{distance}) & \text{if distance} > 1.2 \text{ miles} \end{cases}$$

No information was provided on the degree to which this relationship fit the distance and time data.

A supplemental analysis of these New York data also was performed to determine whether response was affected by time of day. Results showed that only small deviations from the city-wide average response velocity of 18.3 miles per hour were experienced. Averages for all hours fell between 16.2 and 19.2 miles per hour, with the slowest response occurring during the morning rush hour.

In comparing these empirical studies of the relationship between response time and response distance, certain obvious differences in the results can be noted. Hoggs' Glasgow data showed an average response velocity of 19.2 miles per hour, while the data for Wichita Falls suggest that an average velocity of 35 to 45 miles per hour is often observed. Since the New York average of 18.3 miles per hour is fairly comparable with the Glasgow results, it appears safe to conclude that these differences in average velocities are due to the

character of the cities. The urban Glasgow and New York areas could be expected to produce much slower speeds than the smaller city of Wichita Falls.

Of more interest is the close agreement of the results on a number of other matters. New York and Wichita Falls data both suggest a composite time-to-distance relationship like that derived in the New York study. In both cases, response time appeared to grow faster than proportionately to response distance for shorter runs, but reached a proportionate relationship on longer runs. Moreover, the unsatisfactory fits of linear relationships observed by Mitchell might also be due to nonproportionality for shorter distances.

The studies are also in fairly close agreement on time-of-day effects on response time. All studies found relatively small variations in response speeds at different hours of the day. Moreover, the Fullerton and Wichita Falls studies agreed that the only measurable time-of-day effect was a slight decrease in response velocity at night.

Most of the above studies concerned the relationship between response time and actual distance. However, in evaluating the response time performance of a proposed allocation plan, it is almost never possible to measure actual distances unless the plan is actually implemented. Thus, most of the literature reviewed for this report has adopted one of two compromise approaches.

The Santone and Berlin [A-51, A-52] study of East Lansing, Michigan; the Metropolitan Dade County, Florida, fire station location procedure [A-65]; and a number of the studies by Jane Hogg in the United Kingdom [A-20, A-21, A-22, A-23] employ a computer representation of the street network. Each major intersection represents a node in the network, and the roads connecting these nodes are the links of the network. Response time is then estimated between all pairs of nodes by assigning average speeds to each link and calculating the minimum travel time path through the network from one node to the other.

This computer network approach certainly would appear to give a reasonably good approximation of response distance and response time.



However, the development of such a network is a very substantial re-search undertaking in itself. If too few nodes are included, the network would be easy to construct, but the quality of the response time estimates would deteriorate. On the other hand, if a very detailed network were to be produced, very few analytic resources might be left over to complete the suppression allocation study. Thus, the computer network approach would appear to be feasible only in cities where the network has already been developed (e.g., for a highway study).

A computationally simpler alternative is the use of one of the two approximate distance measures defined above, i.e., Euclidean or rectilinear distance. If one of these measures is adopted, street networks can be ignored and map coordinates used to calculate distance.

A limited amount of research on the effects of the use of such approximate distance measures was identified for this report. All such research has been concerned with the use of rectilinear distance to approximate actual distance.

The principal empirical study of this type is the work of Mitchell [A-39, A-40] described above. Using data for Fullerton, California, Mitchell found that rectilinear distance more closely approximated actual distance than did Euclidean distance, but that both seriously underestimated actual distance. However, the quality of his regression fit of response time on distance was nearly as good for rectilinear distance as for actual distance.

Larson [A-32] took an entirely theoretical approach to the relation between rectilinear distance and actual distance. Under a number of very strong and unrealistic assumptions, including one that both fire and firestation locations are spread uniformly over the area of a city, Larson calculated the distance effect of a number of physical features which might contribute to differences between rectilinear distance and actual distance.

The first such feature considered was a barrier (e.g., a river) which forced responding units to travel significantly off their rectilinear path if the fire and the responding unit were located on opposite sides of the barrier. The results of this analysis showed

increases of less than 10 percent in travel distance due to barriers crossing as much as one-half the response area.

The second issue investigated was the effect of having to move through a two-way rectangular system of streets instead of directly along a rectilinear path. To reach a fire, the responding vehicle must proceed first to the nearest intersection, then through a rectilinear grid structure of streets to the intersection nearest the fire, and finally to the fire scene itself. Larson's analysis of this case shows a maximum of one-third block increase in the average true distance over the average rectilinear distance can result from moving to and from the intersections in a grid street structure.

Finally, Larson investigated the effect of one-way streets. In an idealized network where every other street is one-way in the same direction, the analysis showed actual travel distance averaged two blocks more than rectilinear distance. However, a 6-7 percent subpart of the responses experienced a longer increase--approximately six blocks. Thus, while the average increase due to one-way streets is relatively small, the increase does become significant in an important minority of cases.

Even though one is based on empirical results and the other on theoretical calculations under severe and unrealistic assumptions, the Mitchell and Larson studies appear to lead to similar conclusions. Neither identified any serious problems with using rectilinear distance in lieu of actual street distance in estimating response times.

This conclusion, together with the mutually consistent results of the empirical time-to-distance studies discussed above, seems to lead to the further conclusion that accurate and convenient procedures for estimating response time are available. A scheme based on rectilinear distance and employing a two-part time-to-distance expression like the one developed by Kolesar and Walker could be expected to give satisfactory results in most fire protection jurisdictions.

## 5.2 DEMAND FOR FIRE SUPPRESSION SERVICES

The demand for fire suppression services is described by the number and severity of alarms received. Areas with infrequent and inconsequential alarms have low demand, while those with high densities of serious alarms have high demand.

The level of such demand provides a criterion for fire suppression forces allocation which is even more obvious than response time. Certainly, as the panel of fire service professionals assembled for this report agreed, relatively more suppression forces should be allocated to areas with high alarm rates and serious fire risks.

Though the principle of using demand in suppression resource allocation calculations is both obvious and well established in applied fire research, the development of quantitative characterizations of demand is much more complex. For demand to be useful as a criterion for allocation decisions, it must be possible to describe demand concisely and accurately in quantitative terms, yet thousands of factors conceivably could affect the demand in a given area. The next several subsections present the more significant attempts to develop efficient characterizations of demand.

### 5.2.1 OCCURRENCE OF ALARMS

The most elementary measure of demand for fire protection services is the number of alarms occurring in different time periods and geographic areas. To characterize such distributions of alarms it is necessary to investigate such questions as (1) "Are alarms concentrated in certain geographic areas of the fire protection jurisdiction?"; (2) "Does the distribution of alarms vary over the hours of the day?"; (3) "Does the distribution of alarms vary over the months of the year?"

Significant empirical studies of such alarm distribution questions were found in six of the sources reviewed for this report. The first of these analyses is part of the work of Valinsky [A-58, A-59] in New York City. Data were obtained from fires reported during the months of March, June, September, and December, 1950. The data then were analyzed by borough of the city and by time of day.

Results of this analysis are shown in Table 5-5. Clearly,

TABLE 5-5. FIRE INCIDENCE IN NEW YORK CITY BY  
HOUR AND BOROUGH (1950)

(Average Number of Fires)							
Time		All Bor- oughs	Man- hattan	Brook- lyn	Queens	Bronx	Rich- mond
(Midnight)	12	3.0	1.0	1.0	0.4	0.5	0.07
AM	1	2.7	1.0	0.8	0.4	0.4	0.09
	2	2.4	0.9	0.8	0.3	0.3	0.09
	3	2.2	0.9	0.6	0.3	0.3	0.05
	4	2.1	0.8	0.7	0.3	0.3	0.04
	5	1.6	0.5	0.5	0.2	0.3	0.05
	6	1.6	0.5	0.5	0.3	0.3	0.04
	7	2.7	0.9	0.8	0.4	0.5	0.12
	8	3.3	1.2	0.9	0.6	0.5	0.08
	9	4.0	1.0	1.4	0.8	0.6	0.16
	10	4.8	1.1	1.5	1.0	0.8	0.40
	11	5.9	1.3	1.8	1.5	0.9	0.40
(Noon)	12	6.9	1.4	2.1	1.6	1.3	0.5
PM	1	7.5	1.7	2.2	1.9	1.2	0.5
	2	7.4	2.0	2.1	1.6	1.2	0.5
	3	8.2	1.5	2.6	1.9	1.4	0.8
	4	9.4	1.8	3.0	2.2	1.7	0.7
	5	9.8	2.2	3.1	2.0	1.9	0.6
	6	8.3	2.2	2.5	1.7	1.4	0.5
	7	7.2	1.9	2.5	1.3	1.2	0.3
	8	7.1	2.2	2.2	1.3	1.1	0.3
	9	6.0	2.0	1.7	1.0	1.1	0.2
	10	4.9	1.6	1.5	0.7	0.9	0.16
	11	3.7	1.3	1.1	0.5	0.7	0.09

(Source: Valinsky [A-58])

substantial concentrations of alarms were observed in both the geographic and the temporal distributions. Significantly greater densities of alarms were reported in the late afternoon hours and in the more densely developed parts of the city.

Mitchell's [A-39, A-40] study of Fullerton, California, provided a more recent investigation of the distribution of fire service demand. A total of 2345 incidents drawn from a three-year period were analyzed. Public assistance calls, car fire alarms, and emergency calls were eliminated, but all other alarms were included.

In order to study the geographic concentration of alarms, Mitchell divided the city of Fullerton into 134 subregions and tabulated the number of alarms in each region. The resulting number of alarms per region varied from a minimum of 0 to a maximum of 98. Thus, significant geographic concentrations were observed.

To evaluate time concentration of the Fullerton alarms, Mitchell grouped his data into four classes of alarms--residential fires, industrial fires, grass and trash fires, and false alarms. Results for these four classes in the day (7 AM to 11 PM) and night (11 PM to 7 AM) periods are shown in Table 5-6. Clearly, a very significant concentration of alarms was observed in the daytime hours. Moreover, this concentration applied for all types of fires.

Using the same classification of alarms, Mitchell also studied the distribution of alarms over the year. Results of that analysis are shown in Table 5-7. Though not as striking as time-of-day differences, statistically significant variations by month of the year can be seen in these data. Peak periods occur during the summer and winter months, with lower rates during the spring and fall. Concentration in the summer months appears to be largely due to grass and trash fires, while that of the winter months is a combination of increased residential fires and false alarms.

Pinnell-Anderson-Wilshire Associates' [A-64] study of Wichita Falls, Texas, included an analysis similar to Mitchell's. The study was based on 9481 alarms answered during the 1964-1968 period. All types of alarms were counted, including grass, structure, auto and trash fires, false alarms, and nonfire alarms.

TABLE 5-6. DISTRIBUTION OF FULLERTON, CALIFORNIA,  
ALARMS BY DAY AND NIGHT

	Day	Night	Total
Residential	362	80	442
Industrial	186	40	226
Grass-Trash	730	72	802
False Alarm	771	104	875
Total	2049	296	2345

(Source: Mitchell [A-40])

TABLE 5-7. DISTRIBUTION OF FULLERTON, CALIFORNIA,  
ALARMS BY MONTH OF THE YEAR

Month	Residential	Industrial	Grass- Trash	False Alarm	Total
January	43	22	44	88	197
February	42	21	36	51	150
March	38	26	46	63	173
April	35	19	54	67	175
May	30	17	84	60	191
June	29	15	91	65	200
July	28	26	125	86	265
August	36	15	78	65	194
September	34	17	54	62	167
October	27	10	79	76	192
November	50	16	53	79	198
December	49	22	57	106	234
Total	441	226	801	868	2336

(Source: Mitchell [A-40])

To study the geographic distribution of these alarms, they were grouped into traffic districts established by the Texas Highway Department. The number of alarms falling into such districts ranged from 1 to 502, suggesting a very significant concentration of alarms by geographic area.

Figure 5-4 shows the results of analysis of these Wichita Falls data for variations by time of day. As illustrated in that figure, the total number of alarms shows a very great variation over the hours of the day. The highest alarm rate occurs during the daytime hours. However, the figure also illustrates that a significant cause of this variation is the very high rate of grass fires during the afternoon hours. Structure fires are spread much more evenly over the hours of the day.

Figure 5-5 shows the distribution of the Wichita Falls alarms by month of the year. From the figure it is evident that substantial variations in alarm rates were observed for the different parts of the year. Peak periods occur in the summer and winter months, with lower numbers of alarms in the spring and fall. However, the curve for grass fires in Figure 5-5 illustrates that a very significant part of this variation is due to grass fires. Structure fires are much more evenly distributed over the year.

Pinnell-Anderson-Wilshire also performed an analysis of the Wichita Falls alarms by day of the week. The results of this analysis are shown in Figure 5-6. Though some increase was observed on Saturday, this analysis indicated that alarms in Wichita Falls are distributed fairly evenly over the week.

A third empirical study of the distribution of alarms was performed by Nilsson and Swartz [A-41] on data from Alexandria, Virginia. Information was collected on all alarms responded to by an engine or ladder company during the months of May-August, 1970. Thus, while the total number of alarms (961) is sufficient for analysis, some bias of results might be expected because data were limited to summer months.

To analyze the geographic distribution of these alarms, the land area of the city of Alexandria was divided into 1500-square foot areas, and the number of alarms in each area tabulated. Results of this

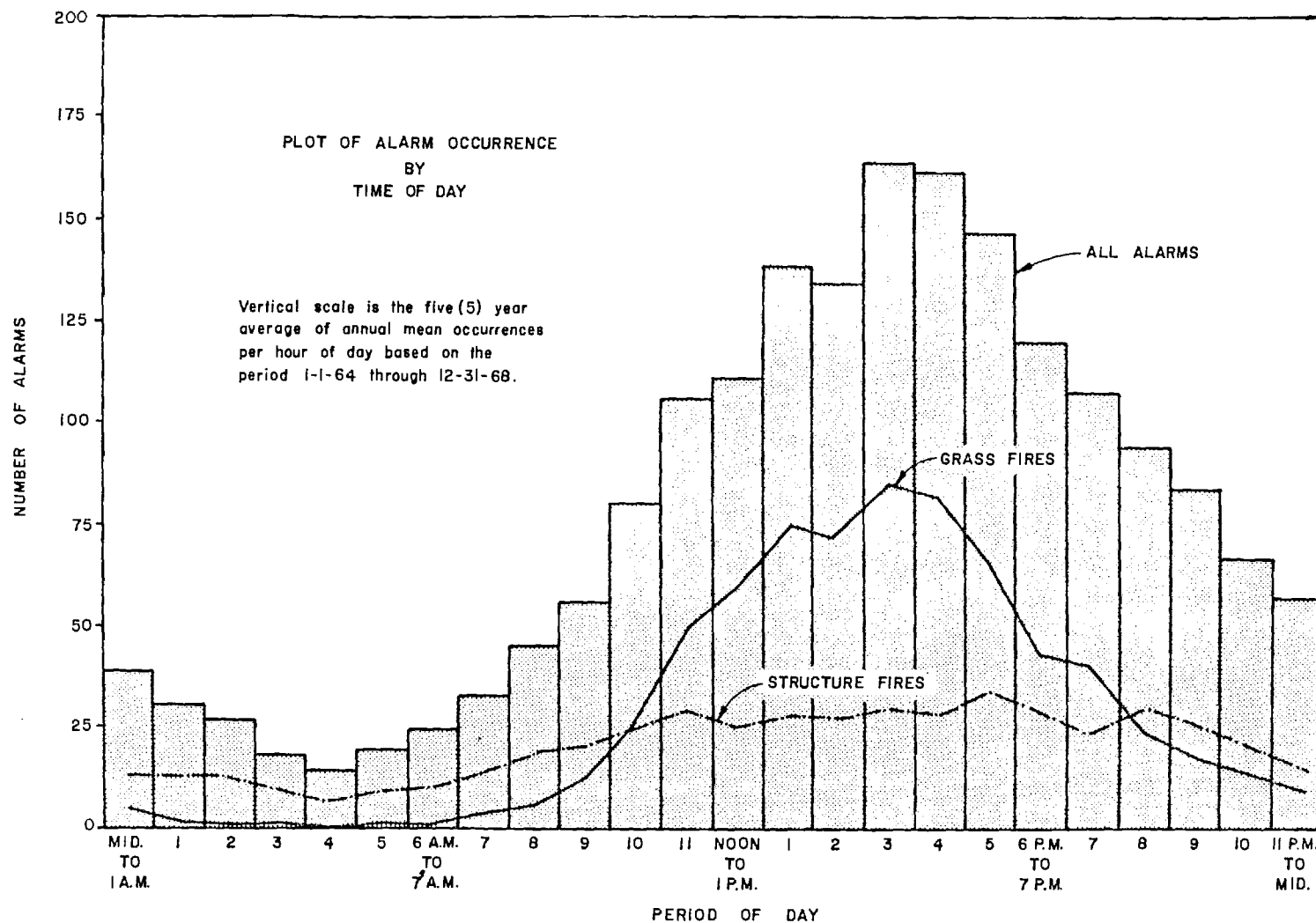


FIGURE 5-4. DISTRIBUTION OF WICHITA FALLS, TEXAS, ALARMS BY TIME OF DAY

(Source: Pinnell-Anderson-Wilshire [A-64])



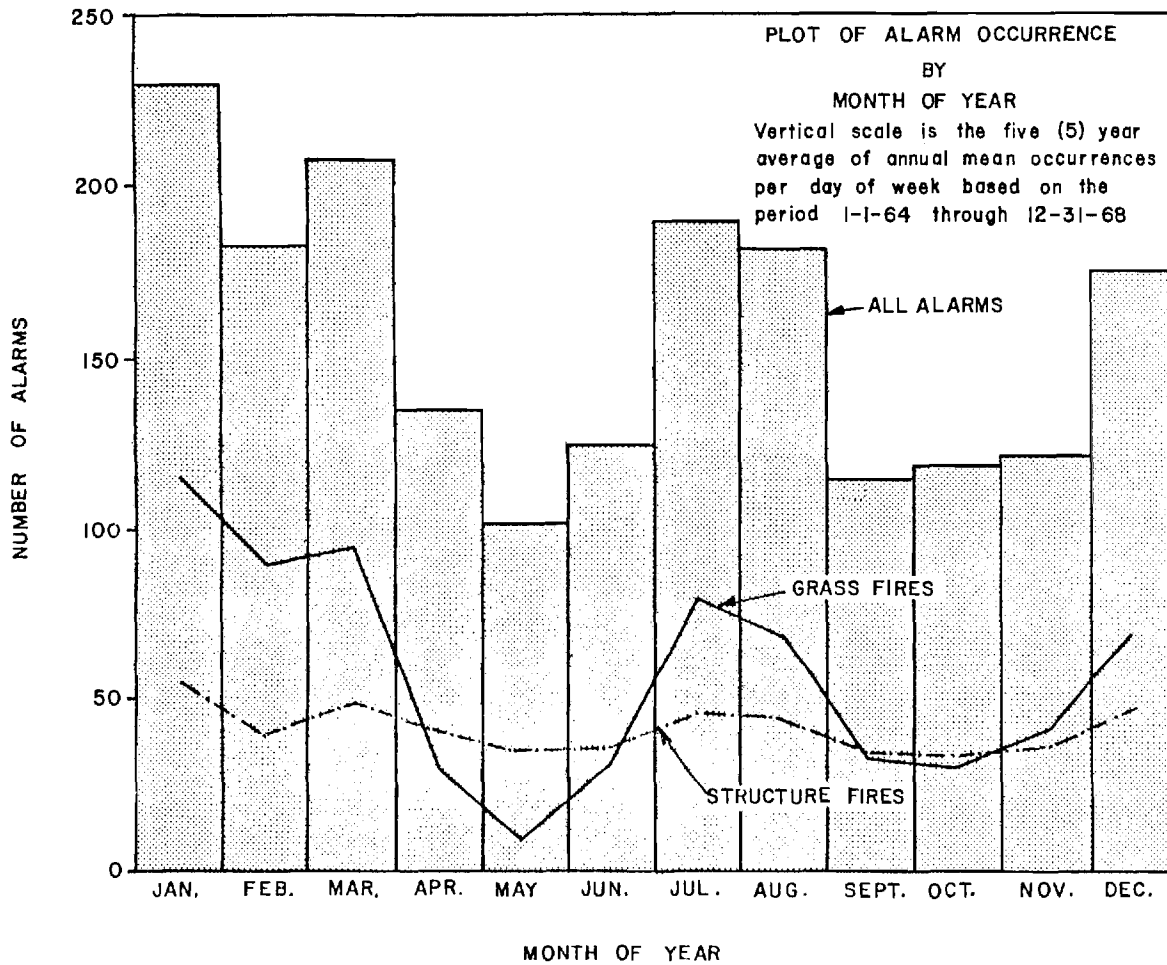


FIGURE 5-5. DISTRIBUTION OF WICHITA FALLS, TEXAS  
ALARMS BY MONTH OF YEAR

(Source: Pinnell-Anderson-Wilshire [A-64])

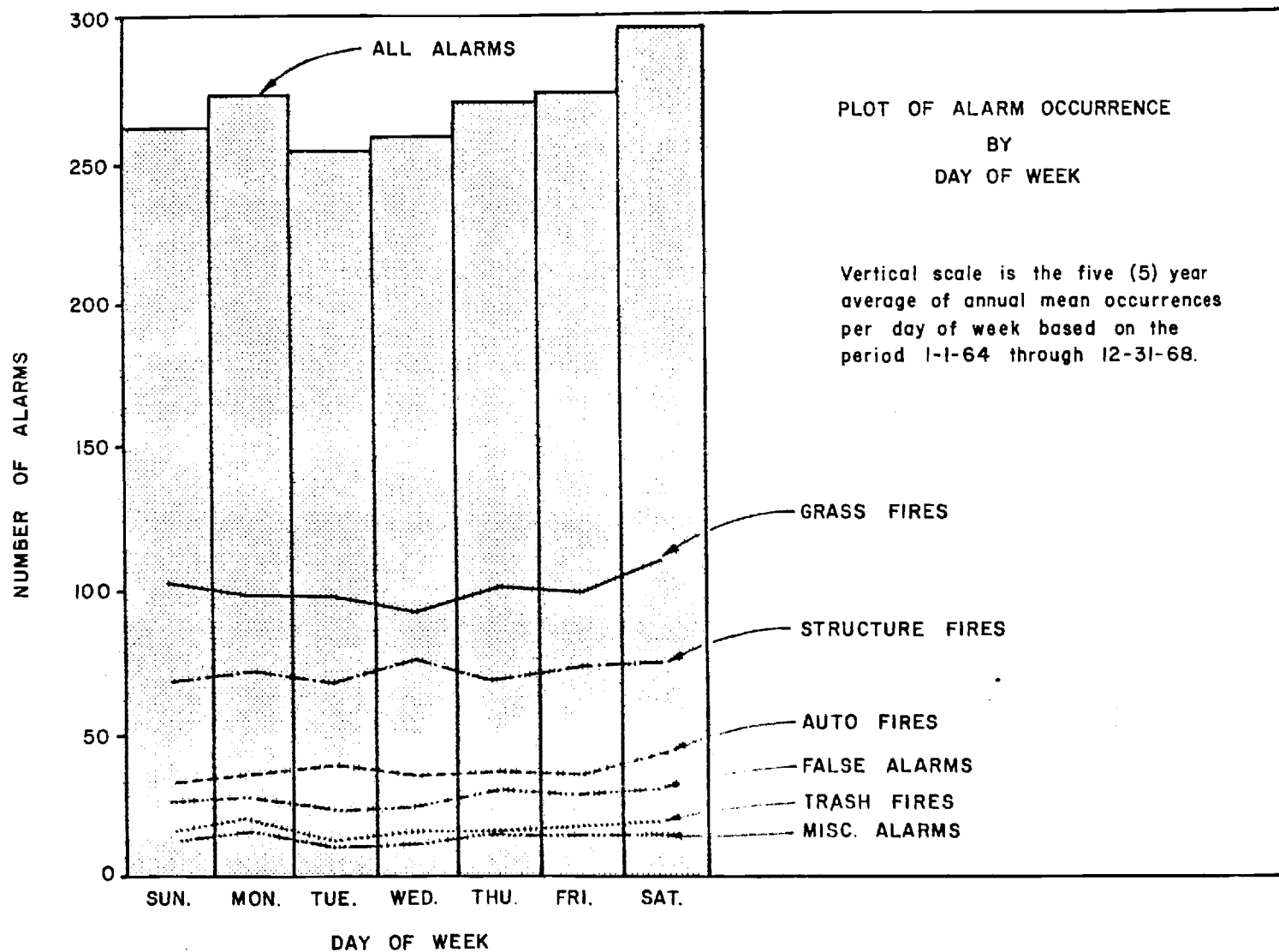


FIGURE 5-6. DISTRIBUTION OF WICHITA FALLS, TEXAS, ALARMS BY DAY OF WEEK

(Source: Pinnell-Anderson-Wilshire [A-64])

analysis showed that the number of alarms per area ranged from 0 to 62, thus indicating a substantial geographic concentration of alarms in certain areas.

Like the other cities discussed above, the Alexandria study also included an analysis of alarms by time of day. Figure 5-7 shows the results of this analysis. Clearly, a substantial variation in the frequency of alarms by time of day was observed. However, the peak hours for the Alexandria area were the evening hours. Half the alarms occurred between 5 PM and midnight.

The Alexandria study also investigated a dimension of the distribution of alarms not included in the previously described research. In addition to the consideration of average alarms rates in different areas and times, Nilsson and Swartz also considered the variability of alarm rates. Figure 5-8 illustrates the results of one such analysis. It shows the number of days on which various numbers of calls were received. While the number of calls per day averaged 7.73, the number of calls on particular days ranged from 0 to 17.

In order to understand this variability more thoroughly, Nilsson and Swartz attempted to fit their data to the Poisson probability distribution, which is the theoretical distribution arising from the assumption that individual alarms occur randomly over time but in a fixed density. A finding that the Poisson distribution is appropriate leads to many mathematical simplifications in the analyses to be presented in the next chapter. While the details of Nilsson and Swartz's analysis cannot be reviewed because they were omitted from the report, the authors claim their data did satisfy statistical tests for a good fit to the theoretical distribution.

The final, and by far the most comprehensive, empirical analysis of alarm distributions reviewed for this report is the work of the Rand Institute in New York City. Swersey [A-55] collected a limited amount of data in Brooklyn in 1968, and Carter and Rolph [A-9] analyzed a massive sample consisting of all fire alarms for the Bronx from 1964 through 1970.

Swersey addressed the question of whether alarms followed the Poisson distribution. Figure 5-9 shows the observed and theoretical

<u>Hour</u>	<u>Number of Calls Occurring in Hour</u>	<u>Fraction of Total Number of Calls</u>	<u>Hour</u>	<u>Number of Calls Occurring in Hour</u>	<u>Fraction of Total Number of Calls</u>
1	50	0.052	13	36	0.038
2	38	0.040	14	59	0.061
3	30	0.031	15	50	0.052
4	24	0.025	16	48	0.050
5	13	0.014	17	33	0.034
6	7	0.007	18	73	0.076
7	8	0.008	19	50	0.052
8	15	0.016	20	63	0.066
9	22	0.023	21	49	0.051
10	24	0.025	22	70	0.073
11	29	0.030	23	62	0.065
12	36	0.038	24	72	0.075

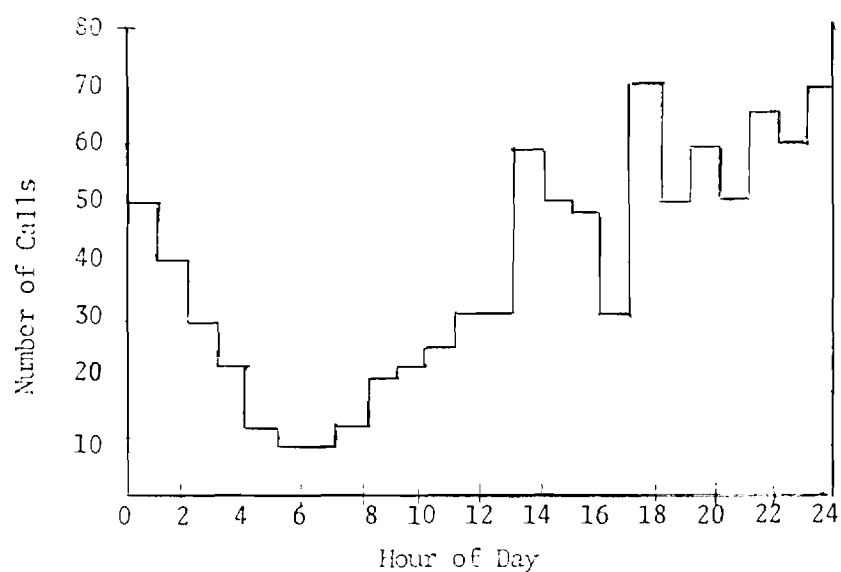


FIGURE 5-7. DISTRIBUTION OF ALEXANDRIA, VIRGINIA, ALARMS BY  
TIME OF DAY

(Source: Nilsson and Swartz [A-41])

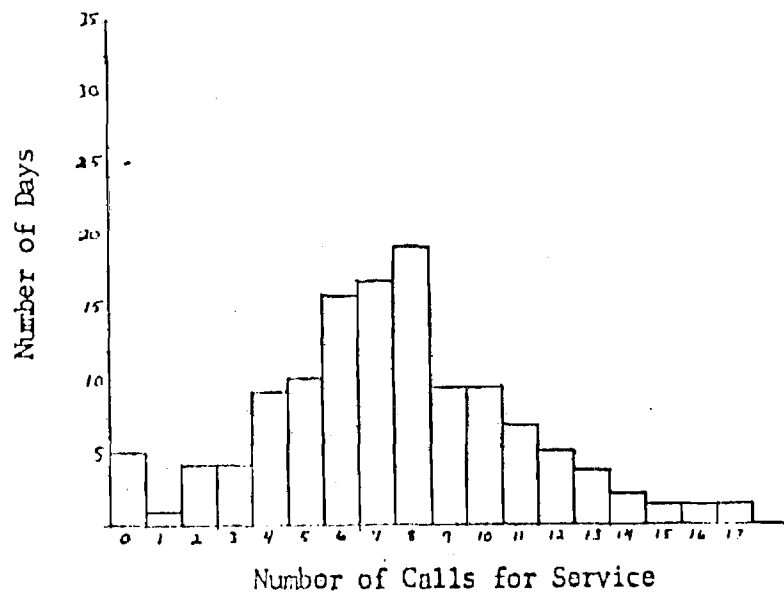


FIGURE 5-8. VARIATION OF DAILY CALLS IN  
ALEXANDRIA, VIRGINIA  
(Source: Nilsson and Swartz [A-41])

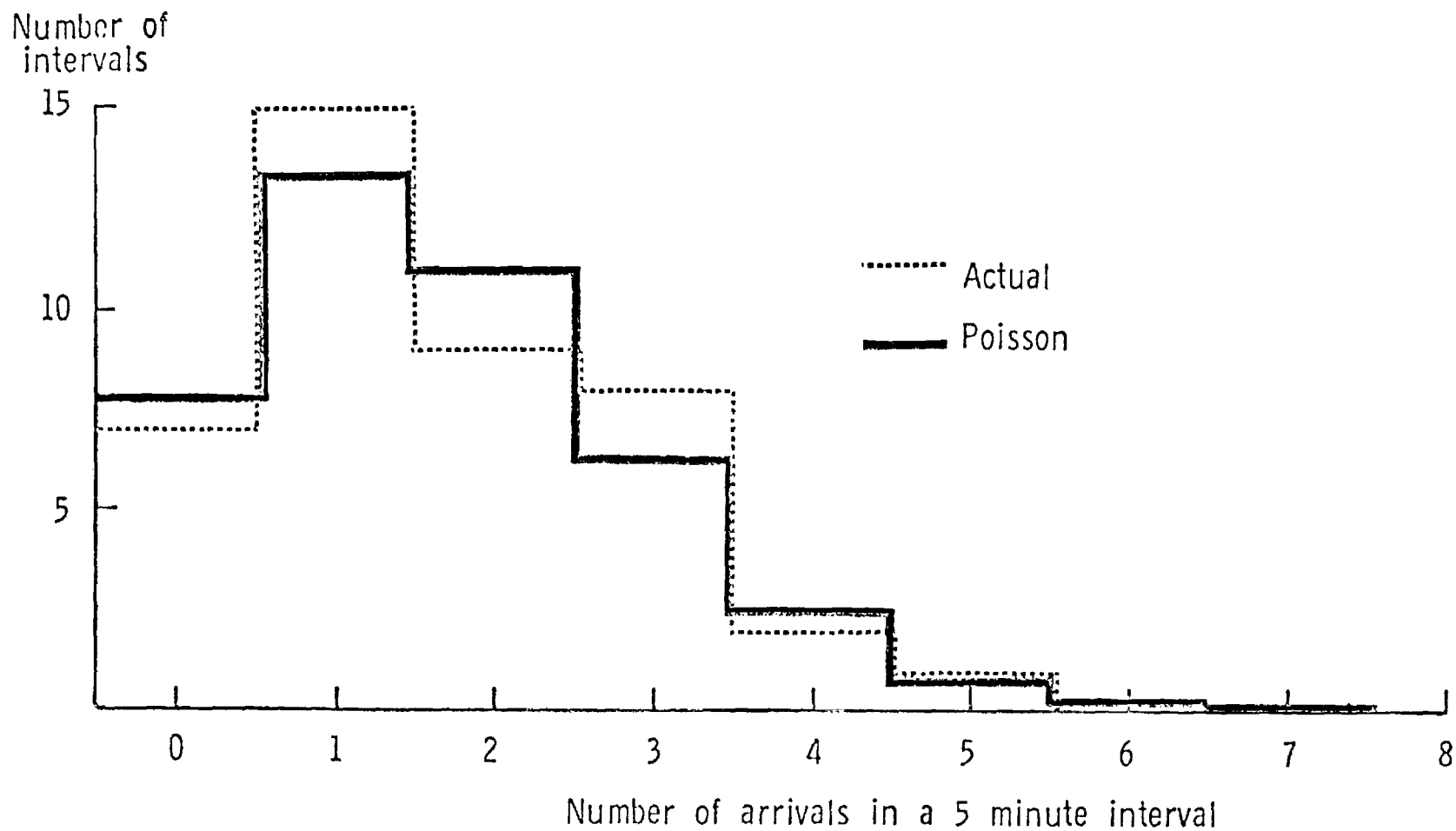


FIGURE 5-9. COMPARISON OF POISSON AND ACTUAL ALARM VARIATION IN NEW YORK CITY

(Source: Swersey [A-55])

numbers of alarms occurring during various five-minute time periods. The apparent closeness of the actual and Poisson distributions were verified by an appropriate statistical test. Thus, the New York alarm rates appear to follow the Poisson distribution.

Unlike some of the other studies discussed so far, the goal of the Carter and Rolph review of Bronx data was to produce a forecasting relationship which would predict accurately the number of alarms in any given hour and region. Thus, their research approached the study of alarm rate distributions by attempting to fit statistical relations instead of merely analyzing variations.

The forecasting approach pursued by Carter and Rolph involves a sequence of estimation stages. First, a procedure was developed to predict the number of alarms on each day in a given (relatively large) hazard region. Second, the fraction of alarms occurring at each hour of the day was estimated. Application of this fraction to the predicted daily alarms yields a basic forecast for the given hour and region. Finally, a smoothing step is applied which adjusts the basic forecast for short-term increases and decreases in the alarm rate.

The development of the appropriate mathematical expression for each of these stages was accomplished with a variety of statistical regression techniques. Alternative mathematical forms were proposed, and necessary parameters for each were estimated from 1964-1969 data. The "best" forms were then selected on the basis of the accuracy with which they forecast 1970 experience.

Many steps in this process of estimating parameters and comparing results cannot be evaluated because they are not documented in Carter and Rolph's paper [A-9] on the analysis. However, the authors report reaching the following conclusions:

- Best regression results are obtained when the number of alarms in an area and time is estimated by expressing its square root as a sum of terms for various effects having a significant impact on alarm rates. In particular, estimating the square root of the number of alarms is superior to either estimating the number of alarms directly or estimating the logarithm of the number of alarms.

- Estimation of the square root of the daily number of alarms requires terms to adjust for a long-term trend, day of the week, and week of the year.
- Daily alarm patterns on Monday through Thursday are essentially the same, but all other days produce different patterns. Thus four different day of the week effects must be included in the expression for the daily alarm rate (weekdays, Friday, Saturday, and Sunday).
- Separate estimating procedures are required for each hazard area because of variations in both the number and pattern of alarms.
- Estimation of individual types of alarms separately and summing to yield total alarms did not significantly improve the quality of the estimates over those obtained by working directly with total alarms.
- Explicit adjustment for weather conditions is not necessary in forecasting alarms if short-term variations in alarms are provided for via smoothing of variations from the usual pattern.
- Estimation of the fraction of alarms occurring in any hour requires adjustment for day of the week and week of the year. However, the weekdays (Monday through Thursday) have a single pattern of variation.

Table 5-8 summarizes the findings of the Fullerton, Wichita Falls, Alexandria, and New York studies of alarm distribution. From this summary it is clear that the results observed by the various researchers in quite different cities are generally consistent. All studies investigating variations in alarm rates by geographic area, time of day, or time of year agree that significant variations exist. Moreover, the two studies addressing the appropriateness of the Poisson distribution to describe alarms agree that the distribution is a good fit.

The major disagreements between the studies concern the nature of the time of day pattern and the existence of day of the week effects. While all studies found significant time of day effects, the Fullerton and Wichita Falls data indicate higher rates in the daytime, while the Alexandria study found concentrations in the evening hours. This disparity very likely is accounted for by the differences in character



TABLE 5-8. COMPARISON OF EMPIRICAL STUDIES OF ALARM RATES

Issue	Fullerton, California	Wichita Falls, Texas	Alexandria, Virginia	New York, New York
Geographic Variation	very sig- nificant	very sig- nificant	very sig- nificant	significant
Time of day Variation	very sig- nificant with high in daytime	very sig- nificant with high in daytime	very sig- nificant with high in evening	significant
Day of the week Variation	not studied	relatively insignifi- cant	not studied	significantly different on weekends
Time of year Variation	significant with peaks in summer & winter	significant with peaks in summer & winter	not studied	significant
Poisson Alarm Distribution	not studied	not studied	acceptable fit	acceptable fit

of the cities concerned. Fullerton and Wichita Falls are smaller cities with relatively low population densities, while Alexandria is part of a dense metropolitan area (Washington, D.C.). More grass and similar daytime alarms could be expected in the less dense cities, while more structure and other night alarms might be expected in the large metropolitan areas.

A similar explanation could be offered for the variation between Wichita Falls and New York on the significance of a day of the week effect. Certainly New York City with its large commuter populations, etc., could be expected to observe greater differences between weekdays and weekends than Wichita Falls.

#### 5.2.2 SERIOUSNESS OF ALARMS

In constructing a measure of demand for suppression services as a criterion for allocation of fire suppression resources, many authors have suggested that consideration of only the number of alarms in given areas is inadequate. They argue that attention must also be given to the seriousness of the alarms. Thus, the risk in a given area is described in terms of both the chances of fires occurring and the likely size of fires if they do occur.

5.2.2.1 OVERALL INDICES OF SERIOUSNESS. None of the studies surveyed for this report included truly empirical research on the characterization of this seriousness aspect of demand. Instead, the analysis has focused on the design of heuristic indices of fire seriousness which officials in the particular city being studied would find satisfactory.

The most elementary approach to development of such an index of fire seriousness is the one discussed by Rider [A-49] and employed by Raouf [A-47] in Windsor, Canada. For Raouf's analysis, the city of Windsor was divided into grid squares with an area of one-fifth square mile each. Records of fires over the past several years were then reviewed, and the total man-hours spent fighting fires in each grid square were calculated. Raouf employed these man-hour totals as a measure of the demand for fire service in each grid area.

In order to be useful as a criteria for fire company allocation,

Raouf's approach requires acceptance of the assumption that the number of man-hours spent fighting fires in a given area is independent of the present location of fire-fighting companies. Since the evidence of Section 5.1.2 strongly suggests that fire suppression resource requirements increase with response time, such an assumption is suspect. The number of man-hours spent fighting fires in a particular area may be as much a consequence of the present distance of that area from a fire station as the seriousness of fire risk in the area.

Stacey [A-53] considered two other simple measures of the fire risk in a neighborhood. He argued that the fire risk should be proportional to the size of the things protected. Thus, he suggested using the population of a neighborhood and the value of the property in a neighborhood as surrogate measures of the fire risk. Both measures were calculated for each of 44 areas in Dayton, Ohio, and a weighted sum of the two used as a criterion for positioning suppression companies.

Stacey's approach would not seem to be subject to the same biases as Raouf's. Population and property distributions are unlikely to be affected by the allocation of fire suppression resources. However, it also seems likely that these aggregate measures would provide only a crude indication of fire hazard. The models of total fire protection costs discussed in Chapter 2 found only weak connection between population, property, and fire loss.

A much more detailed approach was employed by Valinsky [A-58, A-59] in New York City. A "fire hazard" index was first estimated for each type of land use in the city. This index represented the average number of thousands of square feet of property having a particular land use per reported fire. Values obtained for different land uses are shown in Table 5-9.

A second step was the calculation of a "fire proneness" index which reflected the occupancy of various buildings. This index was calculated by dividing the average number of buildings with a particular occupancy which reported fires in 1950 by the total number of such buildings. Typical results are shown in Table 5-10.

Valinsky then used a combination of these two indexes to estimate the risk in a neighborhood. Land use and occupancy were determined

TABLE 5-9. CALCULATION OF NEW YORK CITY HAZARD INDEX

Type of occupancy	Acreage (thousands of sq ft)	Average number of fires per year	Fire- hazard index <sup>1</sup>
1- and 2-family dwellings	10,498	126	83.3
Multiple dwellings	131,116	5,759	22.8
Office and store buildings	24,263	468	51.8
Warehouses and lofts	35,240	729	48.3
Auto storage and service	11,413	68	167.8
Heavy industry	5,489	104	52.8
Public buildings	56,933	126	451.8
Transportation	14,723	229	64.3
1. One fire for each X sq ft of type of occupancy (X expressed in terms of thousands of sq ft).			

(Source: Valinsky [A-58])

TABLE 5-10. NEW YORK CITY FIRE-PRONENESS INDEX FOR SELECTED OCCUPANCIES

Type	Ratio of fires to 1000 structures	Type	Ratio of fires to 1000 structures
Dwellings	0.3	Printing & publishing	1.5
Tenements	8.2	Paper & allied trades	3.8
Warehouses	9.3	Men's suit factory	1.9
Factories	6.9	Textile mills	3.5
Garages	1.4	Grocery stores	1.8
Hotels	36.1	Restaurants	4.2
Theaters	9.0	Men's clothing manu- facturer	4.7
Store buildings	1.4	Drug stores	1.4
Loft buildings	10.6	Tailor shops	1.1
Churches	1.8	Barber shops	0.2

(Source: Valinsky [A-58])

from available planning records, and multiplication by the appropriate fire hazard and fire proneness indices produced an overall indication of the seriousness of the risk.

Santone and Berlin [A-52] considered several similar approaches to calculating indices of seriousness in their study of East Lansing, Michigan. They first suggested attempting to estimate the risk at each individual structure from historical data by statistical regression on characteristics of the structure (number of residents, floor space area, etc.). However, this procedure was not pursued because sufficient data were not available. Moreover, the approach would have been subject to the same limitations as Raouf's method. Analysis in Section 5.1.1 indicates that historical fire losses in a neighborhood are partially a consequence of the present location of fire companies.

The second approach attempted by Santone and Berlin was to derive subjective measures of the risk at various types of structures (schools, hospitals, single-family dwellings, etc.) on the basis of rankings by members of the city staff and research analysts assigned to the project. This approach also was rejected because sufficient uniformity could not be obtained in the rankings proposed by the various participants.

A third approach involved an effort to make the subjective evaluations more systematic. Statistical regression was performed to express the average subjective risk assigned in the previous analysis in terms of the characteristics of typical structures of each type. The characteristics considered included the number of persons endangered, the number of floors in building, construction type, area of the structure, and area of each floor.

While results from this statistical analysis were considered inadequate, the approach ultimately adopted closely parallels the statistical approach. In lieu of the weights derived through regression, subjective weights were developed for each of the above characteristics of buildings. These weights were then applied to typical specifications for various types of structure. Thus, the index of seriousness ultimately proposed by Santone and Berlin involved a structure-by-structure analysis of risk, with the risk at each structure being developed by

subjectively weighing a number of relevant characteristics of the building. The authors report that this approach produced results acceptable to city officials in East Lansing in spite of its informality.

An approach very similar to the one ultimately employed by Santone and Berlin is part of the location procedure developed in Metropolitan Dade County, Florida [A-65]. For this procedure, fire service officials were asked to provide "desired response times" to each section of the county. The times thus represented the officials' professional judgment on the hazard or risk in each section.

Analysts from the National Bureau of Standards then correlated these subjective estimates of the risk in each area with a number of land use statistics. Those ultimately found important in predicting desired response time were the following:

- the density of permanent (noncommuter) population in the area,  $(X_1)$
- the density of commercial, manufacturing, and industrial land use,  $(X_2)$
- the density of institutional land use,  $(X_3)$ , and
- the density of park land use,  $(X_4)$ .

Statistical regression on these factors produced the equation

$$\begin{array}{l} \text{Desired Travel} \\ \text{Time} \end{array} = 4.42 - .0518 X_1 - 2.69 X_2 - 5.59 X_3 - 1.47 X_4.$$

Still another subjective assessment of fire seriousness was part of the Pinnell-Anderson-Wilshire Associates [A-64] study in Wichita Falls. The approach was to divide the city into a series of fire analysis zones. The fire hazard for each of these zones was then estimated by weighting subjective estimates of a number of risk characteristics of the zones. Weights apparently were also derived subjectively, but no details are given in the project report.

The zone characteristics considered in the Wichita Falls hazard rating were grouped into two categories--damage potential from a given fire, and fire spread potential that a particular fire might develop into a major conflagration. Table 5-11 lists the component

TABLE 5-11. ELEMENTS OF WICHITA FALLS, TEXAS, HAZARD RATING

#### Fire Hazard Ratings

After Fire Analysis Zones are established, then each zone would be studied and a numerical hazard rating would be assigned to each zone for each of the following types of alarms:

- Structure Alarms
- Auto Alarms
- Grass Alarms
- Other Alarms

The Hazard Rating would be based upon the following two major factors:

- Damage Potential - The potential for a given fire to inflict economic loss and to cause deaths of injuries.
- Fire Spread Potential - The potential for a given fire to spread and to inflict major damage.

Techniques for assigning a numerical rating to the above factors by fire type will be discussed in the following sections.

#### DAMAGE POTENTIAL

This rating will consider the potential of a given alarm to inflict damage at its site. This damage potential will be considered in terms of:

- Potential Deaths and Injuries
- Potential Economic Loss

These factors will be evaluated for each type of fire as follows:

#### Potential Deaths and Injuries

- High - The zone has a high population density and/or a large number of schools, hotels, hospitals, apartment buildings, etc., where large numbers of people are involved and the potential for being trapped and injured by fire is great.
- Medium - The zone has medium to high population density and/or a considerable number of schools, hotels, hospitals, apartment buildings, etc., where large numbers of people are involved and the potential for being trapped and injured by fire is great.



TABLE 5-11. (CONTINUED)

- Low - Has low density with few or no schools, hotels, majority single family residenceals, etc.

#### Economic Loss

- High - The initial fire has a high probability of causing an economic loss of \$50,000 or greater.
- Medium - The initial fire has a high probability of causing an economic loss of from \$10,000 to \$50,000.
- Low - The initial fire has a high probability of causing an economic loss of less than \$10,000.

#### FIRE SPREAD POTENTIAL

This rating will measure the potential of a given fire in the zone to spread to other buildings in the zone and inflict major damage. This fire spread potential will be measured in terms of the following factors:

- |                          |                                    |
|--------------------------|------------------------------------|
| • Density of development | • Building structure type          |
| • Age of structures      | • Building attic type              |
| • Type of initial fire   | • Explosive or flammable materials |
| • Building roof type     |                                    |

These factors will be evaluated for each type of fire as follows:

#### Density of Development

- High - High density building development. Closely spaced multi-story building typical of mercantile or heavy commercial-industrial area.
- Medium - Medium density building development, such as usually found in residential areas.
- Low - Low density of building development with large tracts and high percentage of vacant land.

#### Type of Initial Fire

- High - Structure fire
- Medium - Grass fire

TABLE 5-11. (CONTINUED)

- Low - Auto or other fire

Age of Structures

- Medium - Average age of structures is from 15 to 30 years.
- Low - Average age of structure is less than 15 years.

Building Roof Type

- High - Less than 40 percent of the buildings have roofs constructed of fire resistive materials.
- Medium - From 40 percent to 75 percent of the buildings have roofs constructed of fire resistive materials.
- Low - More than 75 percent of the buildings have roofs constructed of fire resistive materials.

Building Structure Type

- High - Less than 40 percent of the buildings are constructed of fire resistive materials.
- Medium - From 40 percent to 75 percent of the buildings are constructed of fire resistive materials.
- Low - More than 75 percent of the buildings are constructed of fire resistive materials.

Building Attic Type

- High - More than 75 percent of the buildings are connected with a common attic.
- Medium - From 40 percent to 75 percent of the buildings are connected with a common attic.
- Low - Less than 40 percent of the buildings are connected with a common attic.

Explosive Flammable Materials

- High - High probability that fire in zone could ignite explosive or flammable materials.

TABLE 5-11. (CONTINUED)

- Medium - Small probability that fire in zone could ignite explosive or flammable materials.
- Low - No explosive or flammable material in zone.

(Source: Pinnell-Anderson-Wilshire [A-64])

characteristics included in each of these major categories.

In contrast to some of the other approaches which focused exclusively on structure fires, fire hazard was estimated for all types of alarms in Wichita Falls. Specifically, separate estimates of each of the factors in Table 5-11 were made for structure fire alarms, grass fire alarms, auto fire alarms, and other alarms. Overall fire hazard in a fire analysis zone then was calculated as the sum of ratings for individual fire types, weighted by the number of such fires in the zone over the past several years.

In each of the above cases, the authors commented that their approaches were only a beginning on the problem of estimating the seriousness of fire risk in a given area. It is certainly true that the approaches are subject to a number of criticisms. Studies which attempt to use prior fire history as a measure of hazard run the risk of ignoring the relationship between current resource allocations and size of fire losses. Approaches which focus on individual structures require such exhaustive amounts of data that resort to some sort of heuristic simplification is almost required. On the other hand, estimating hazard on an areawide basis introduces even more subjective opinion and approximation into the process of developing a criterion for suppression resource allocations. It would appear that considerable research could be profitably addressed to the development of better measures of the seriousness aspect of fire suppression service demand.

5.2.2.2 STUDIES OF SPECIAL RISKS. The hazard or seriousness indices discussed in the previous subsection addressed overall risk for an area of a city. As background research for development of measures of fire demand, as well as for selection of appropriate fire inspection standards, it would seem that profitable research might be directed at the narrower question of the risk with particular structures or hazards. In fact, many persons have collected various statistics on the hazards of particular structures. However, only one study was identified in connection with this report which was genuinely research, i.e., it proceeded beyond mere statistics collection to a point of forecasting

future risks.

This study, which was performed by the British analysts Baldwin and North [A-4], investigated the fire hazard associated with large shopping malls. The researchers used data compiled on the 5580 fires in British shops during 1967 to forecast the fire risk in malls containing many shops.

The analysis proceeded by assuming that the combined hazard associated with a large number of shops in a shopping mall can be approximated by combining the experience of an equal number of separate shops located throughout the country. As the authors note, this assumption could be considered suspect on a number of grounds. For example, modern building codes and materials might make experience with new shopping malls quite different from experience with other, older shops. Moreover, the limited ingress and egress associated with shopping malls might produce new threats not observed in separate shops.

Within the limitations of this assumption, however, Baldwin and North calculated a number of elements of fire risk in shopping malls. The most important of these are the following:

- The historic annual risk of fire in any shop is 0.01. This implies<sup>1</sup> an annual risk of fire of 0.90 for a shopping mall with 200 shops, i.e., it is almost certain that at least one fire will occur during the year.
- The above risk for a mall of 200 shops implies<sup>2</sup> an average of one fire each six months. Moreover, data on the time of day of fires in existing shops suggest this fire rate can be decomposed into an average of one fire every 0.9 years during

- 
1. Using the probability of a fire in a single shop equal to  $p$ , the probability of at least one fire in 200 shops is  $1 - (1 - p)^{200}$ .
  2. An annual probability of fire of 0.01 implies a mean time between fires of  $.99/.01$  or approximately 100 years. For 200 shops, this figure is divided by 200 to obtain the average time between fires.

shopping hours (8 AM to 6 PM), one fire every 1.3 years during evening hours (6 PM to midnight), and one fire every 3.6 years during night hours (midnight to 8 AM).

- Historic data suggest the risk of a serious fire is greatly increased during the night hours.
- The number of persons who might be in shops of a mall when a fire occurs suggests the rate of personal injuries in shopping malls of 200 shops would be no higher than that of persons in their own homes.

### 5.3 OTHER INDIVIDUAL RISK CRITERIA

Response times to fires, together with the number and seriousness of fires, are by far the most commonly employed criteria for measuring the level of fire suppression service provided to an individual area. However, a number of other measures have at least been proposed. In this section, those measures will be briefly considered.

#### 5.3.1 INSURANCE STANDARDS

For many years, the American Insurance Association, formerly the National Board of Fire Underwriters, evaluated fire departments as part of its role in the establishment of fire insurance rates. More recently, such evaluation has been assumed by the Insurance Service Office (ISO), but the rating procedure is substantially unchanged. The ultimate rating received by a city depends on a host of elements, including its water supply and fire alarm system, as well as the capabilities of its fire department.

The portion of the ISO system concerned with suppression resources allocation is based on a series of maximum response criteria. Risks in different areas are estimated in terms of the gallons-per-minute flow required to suppress fires in those areas. In order to obtain a good rating, the fire department being evaluated must have sufficient fire suppression resources to meet the estimated flow located within given response distances from the site of the risk. Sample standards of this type given by Drumm in [5-5] are reproduced in Table 5-12.

TABLE 5-12. TYPICAL ISO DISTANCE STANDARDS

Company Travel Distances			
Type District	Fire Flow Required (gpm)	Distance in Miles	
		Engine Co.	Ladder Co.
High Value	9000 or more	3/4	1
	4500 to 9000	1	1-1/4
	2000 to 4500	1-1/2	2
Residential* (closely built)	Over 2000	1-1/2	2
Residential (well spaced)	1000 to 2000	2	3
<p>*Also applies to districts with three-story or higher buildings, including apartment houses, tenements and hotels. Where the life hazard is higher than usual, the engine and ladder company travel distances should be reduced to 1 and 1-1/4 miles, respectively.</p>			

(Source: Drumm [5-5])

Because of the traditionally large influence of the ISO in planning for fire protection, it has often been suggested that any procedure for evaluating positioning, repositioning, or dispatching plans for fire companies should include these insurance standards as a criterion. Plans which produce high ISO ratings would be considered superior.

However, only a limited and inconclusive amount of research has addressed the appropriateness of such a criterion in helping to achieve the fire service's ultimate goal--reduction of fire loss. Thus, if fire companies were relocated to improve the ISO rating, it is not clear that losses would be reduced. Moreover, the panel of fire service professionals assembled for this research effort found it debatable that insurance response standards should be an important criterion for allocating fire suppression resources. Thus, the usefulness of insurance standards as a criterion for fire suppression resource allocation remains an open research question.

#### 5.3.2 WORKLOAD BALANCE

Much of the recent research on fire company allocation in New York City (see, for example, Ignall [A-25] or Carter, Chaiken, and Ignall [A-5]) has proposed consideration of the workload of fire companies in developing allocation plans. Thus, for example, dispatching rules have been proposed which give consideration, in choosing the units to dispatch, to both the distance of the responding unit from an alarm and the relative workload of nearby units.

Details of these research efforts will be presented in the next chapter. However, the overall implication of the work is that workload balance can be significantly improved with only slight increase in response time.

Unfortunately, though these New York studies indicate workload balance can be improved through proper resource allocation, no research was located in the preparation of this report which sought to evaluate whether workload balance should be a criterion. For example, it would



be useful to know whether workloads are high enough to create a balance problem in many cities. Similarly, it would be helpful to understand how changes in workload might effect the morale and productivity of fire fighters. The Professionals Panel implied these were relevant research questions because they saw as debatable the idea that workload was a problem except in very busy departments like New York's.

### 5.3.3 NONSTRUCTURE FIRE CALLS

Table 5-13 is taken from the Pinnell-Anderson-Wilshire and Associates [A-64] study of Wichita Falls, Texas. It shows the distribution of the 9481 alarms received by the Wichita Falls Fire Department during the years 1964 through 1968.

From the table it is clear that structure fires produce only about one-fourth of the total number of alarms received in Wichita Falls. Moreover, an average of 7.5 percent of alarms did not fall into any of the fire classes. These other alarms consisted principally of rescue operations and related emergency services not connected with fires.

The Wichita Falls data in Table 5-13 illustrate the fact that modern fire departments spend much of their time responding to alarms other than structure fires. Thus, it would seem appropriate to develop resource allocation criteria which explicitly addressed nonstructure fire alarms.

Not only was no research on such special criteria for nonstructure fire alarms located in preparing this report, but the majority of the criteria research discussed in previous sections ignored such alarms altogether. Most researchers have oriented proposed resource allocation criteria toward structure fires. Effects of response time have been largely measured in terms of growth of losses in structure fires; seriousness indices have been designed primarily around risks associated with structures; insurance response standards have addressed principally the response to burning buildings.

The Professionals Panel found debatable the idea that fire calls should be more important than nonfire calls in allocating suppression forces. Thus, it appears that a significant gap in present research may be in concentrating too heavily on structure fire in developing

TABLE 5-13. DISTRIBUTION OF WICHITA FALLS, TEXAS,  
ALARMS BY TYPE

Year	Grass	Structure	Auto	Trash	False	Other	Total
1964	747	577	298	139	152	187	2100
1965	595	498	296	105	189	142	1825
1966	681	472	239	124	185	119	1820
1967	1016	474	251	145	144	140	2170
1968	497	482	227	115	120	125	1566
Total	3536	2503	1311	628	790	713	9481
Percent of Total							
1966	35.6	27.5	14.2	6.6	7.2	8.9	100.0
1965	32.5	27.4	16.2	5.8	10.3	7.8	100.0
1966	37.5	26.0	13.1	6.8	10.1	6.5	100.0
1967	46.8	21.8	11.6	6.7	6.7	6.4	100.0
1968	31.7	30.8	14.5	7.3	7.7	8.0	100.0
Average	37.2	26.4	13.9	6.6	8.4	7.5	100.0

(Source: Pinnell-Anderson-Wilshire [A-64])

criteria for fire suppression resources allocation. Questions which might be addressed include:

- How can the risk or demand for nonstructure fire alarms be estimated?
- How would fire-fighting force locations change if they were positioned to best serve demands other than structure fires?
- What kinds of dispatch rules are appropriate for nonstructure alarms?

#### 5.3.4 DOLLAR COST

It is almost universally agreed that the ultimate measure of the value of a suppression allocation plan is its impact on total cost to society. However, such an all-inclusive concept as societal cost is very difficult to implement as an actual estimating procedure.

Some high level analyses of the cost of fire protection were discussed in Section 2.2. However, these procedures are generally not detailed enough to be suitable for comparing suppression resource allocation plans.

Two authors of research reviewed for this report did, however, propose societal cost criteria which were affected by suppression allocation. One of these is the very simple model of Guild and Rollin [A-16]. This model (discussed in more detail in Section 6.1.1) estimates the average societal cost of assigning a given number of companies to a region to be protected. Included in the average are costs of maintaining the companies and costs due to anticipated fire losses. However, all costs are assumed to be simple multiples of time. Thus, the model is not really an attempt to measure societal cost, but instead a scheme for weighting the impact of the cost to a fire jurisdiction of providing protection against the cost to the citizenry of fire losses. The costs themselves are probably meaningless, but their relative impact is an appropriate consideration in resource allocation.

The second, and much more sophisticated, attempt to measure total societal cost of resource allocation plans found in the literature reviewed for this report is the work of Hogg in the United Kingdom [A-20, A-23]. Costs of providing fire protection were calculated as

the sum of capital costs for constructing facilities and variable costs for operating the facilities. Fire losses were projected as a function of the response time performance of the allocation plan by using a mathematical model of fire spread (presented in [5-9]). The author reports that results derived from this cost-based resource allocation were superior to earlier ones (e.g., [A-22]) based entirely on response times.

Though based on much more empirical information and more exact estimating procedures, it would appear that Hogg's studies also can be viewed as being aimed at developing weighting schemes for response times. If satisfactory information about the nature of the relation between response time and fire growth could be developed, the complex estimation of societal cost would be largely unnecessary.

#### 5.4 COMPOSITE/OVERALL CRITERIA

In order for a criterion to be useful in evaluating proposed suppression forces allocation in any jurisdiction, at least two elements are required. First, it must be possible to evaluate the effect of the proposed plan on individual areas and risks in the jurisdiction; and second, a procedure must be devised for combining these individual measures into an overall evaluation of the plan.

Each of the above sections has addressed particular criteria for evaluation of the effect of a plan on individual areas. In this section, attention will be directed to the problem of combining the individual results to produce an overall criterion.

##### 5.4.1 EXPECTED RESPONSE TIME

Just as response time is by far the most commonly proposed measure of performance of an allocation plan in an individual area, average or expected response time is by far the most commonly proposed method for aggregating individual response times. To calculate an overall measure of the performance of a proposed allocation of fire companies, the response time to each subarea is estimated and an average over all areas is calculated.

In nearly every case (see, for example, Mitchell [A-39, A-40] or Hogg [A-22]), it is proposed that this average be weighted for the number of incidents occurring in the various areas. Thus, the resulting measure is the sum of responses to different areas times the probability that an alarm will originate in that area.

#### 5.4.2 AVERAGING MULTIPLE COMPANY RESPONSES

As observed by Mitchell [A-39, A-40], Carter and Ignall [A-6], and many others, however, there remain a number of difficulties in applying such an aggregate criterion. First is the problem of which response times to average. The designated response to a given alarm may include many different companies. Each of these companies will have a different response time to the scene. If, for example, one allocation plan produces a response time for the first company of two minutes and a response time for the second company of ten minutes, while the corresponding times for an alternative plan are four and eight minutes, it may not be clear which plan is superior.

Many different solutions to this dilemma have been proposed in the research reviewed for this report. The most common method is to consider only the response of the first arriving unit. This approach often greatly simplifies the mathematics in resource allocation procedures. However, the Professionals Panel found debatable the proposition that the response time of the first arriving company should be the principal criterion for fire resource allocation. Certainly such a criterion would be questionable in any jurisdiction with large buildings or industrial complexes which might require large suppression forces.

At the other extreme is the approach used in the New York City-Rand Institute computer simulation for evaluating resource allocation plans (see Carter, Ignall, and Walker [A-7] and discussion in Section 6.4). In this simulation, separate records are maintained of the first, second, third company, etc., on the scene of simulated fires. Fire department decision makers then are required to determine subjectively the best allocation policy on the basis of reported performance for each response.

Most commonly, however, some form of weighting the various response times is employed. For example, Mitchell [A-39, A-40] proposed weighting the second response time by the probability that a second unit would be required at the fire scene. Then, the suppression resource allocation plan was preferred which minimized the average of first response times and the weighting factor times second response times. Similar schemes are reported in many other studies.

One additional approach to the weighting problem is provided by the "protection" concept proposed by Stacey [A-53]. Instead of minimizing the sum of response distances to hypothetical alarms, Stacey proposed maximizing the weighted sum of the reciprocals of response distance. The "protection" provided to a given area under a particular allocation plan is then defined to be the weighted sum of these reciprocals for all fire companies. The effect of this approach is to include the response of all companies in the criterion for resource allocation, but to weight times according to the distance of the company from the alarm. Response distances for closer companies (which presumably would be the first to arrive on the scene) are weighted more heavily than those of distant companies.

In spite of the variety of proposals for dealing with the response times of different companies, no research was obtained for this report which investigated the implications of the various proposals. For example, no research is known which attempts to study the effect on fire growth and fire losses of the response time of the first responding company, versus the response time of other companies. Perhaps more importantly, no research is known which indicates how much optimal allocation plans might be changed if the weight given to different responses is varied.

#### 5.4.3 WEIGHTING FOR SERIOUSNESS

Another issue often raised with respect to averaging response times is consideration of fire seriousness. In Section 5.2.2 a number of studies seeking to develop measures of the seriousness of fire risk in given areas were discussed. The purpose of these studies was to improve the quality of estimates of demand for fire suppression services

by combining the number of alarms in given areas with the expected seriousness of the alarms.

In nearly all these studies, this measure of seriousness was carried through in the calculation of an overall average response performance. The response time to each area of the city was weighted by the expected seriousness of fires in the area to obtain a composite criterion for allocation of fire suppression resources.

Though the procedure of weighting response time averages for seriousness of fires has been suggested in a number of circumstances and implemented in most, no research was located for this report which investigated the implications of such a weighting approach. Relevant questions might include:

- How much does weighting for seriousness change the choice of suppression forces allocation plans?
- Does weighting for seriousness cause the overall average to approximate more closely the total fire loss associated with a given allocation plan?

#### 5.4.4 CONSIDERATION OF AREA EXTREMES

A third difficulty with the use of overall averages as a composite criterion for fire resources allocations is that the averaging process may mask serious inadequacies in particular areas. It is quite possible for the average of any sequence of numbers to be acceptably low when certain of the numbers are quite high. Thus, for example, a fire suppression resource allocation plan which produces the lowest average response many have some areas with very long response times.

Rider [A-49] developed and analyzed an approach to dealing with this undesirable property of average response time. He proposed selecting the number of companies to assign to various areas on the basis of the weighted sum of average response times in the areas raised to a power  $\beta$ .<sup>1</sup> Weights are derived from the estimated number and

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1. Specifically, his formulation was

$$\text{minimize } \sum_i W_i \{t_i\{n_i\}-u\}^\beta$$

(Continued p. 190)

seriousness of alarms in the area.

The exponent  $\beta$  then becomes a measure of the equality of response times in various districts. When  $\beta=1$ , Rider's criterion reduces to the city-wide weighted average response time. When  $\beta$  becomes large, allocation plans with very large response times in some districts rate very poorly because these large times dominate the city-wide average when raised to a large power.

Rider experimented with his criterion on the allocation of ladder companies to a number of districts in New York City. A simple statistical formula derived by Kolesar [A-26] was used to estimate average response time for each district on the basis of the land area of the district, the number of companies assigned to the district, and the typical travel velocity in the district.<sup>1</sup> Weights for the various areas were determined from the average man-hours typically expended by the fire department in the areas.<sup>2</sup>

The results of this analysis are shown in Table 5-14. The number of companies assigned to each hazard region and the resulting response time behavior are presented for several values of  $\beta$ . Clearly substantial reductions in the disparity between the minimum and maximum regional average were obtained at relatively small increases in overall response time. Moreover, variation in  $\beta$  very significantly changes the numbers of companies assigned to different regions.

The inexactness of Kolesar's estimating technique for response times, together with the fact that the study was performed in the

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subject to  $\sum_i n_i = M$

where  $W_i$  = the weight for area  $i$

$t_i \{n_i\}$  = the average response time in area  $i$  if  $n_i$  companies are assigned

$M$  = the total number of companies available

$u$  = the turn-out time of companies.

1. See Section 6.1.1 for detailed discussion of this estimation procedure.
2. See Section 5.2.2.1 for discussion of the limitations of this measure of fire seriousness.



TABLE 5-14. LADDER COMPANY ALLOCATIONS IN NEW YORK CITY  
BY VALUES OF THE PARAMETER  $\beta$

Hazard region	Current policy	Minimum average response time $\beta = 1$	Similar to current policy $\beta = 3$	Equal average response time $\beta \rightarrow \infty$
2	3	3.6	2.5	1.1
6	12	15.0	11.6	5.8
7	2	1.7	1.6	1.2
8	12	8.9	10.6	12.3
9	15	19.8	15.0	7.2
10	15	13.3	14.1	13.0
11	3	1.9	2.4	3.4
12	16	23.1	19.5	11.0
13	6	5.4	6.7	8.7
14	11	9.6	11.9	15.6
15	7	5.5	7.7	13.3
16	4	2.2	2.7	3.5
17	4	4.4	5.0	5.1
19	3	2.3	3.0	4.4
20	4	2.0	3.1	6.8
21	4	2.3	3.6	8.7
Average response time	3.40	3.35	3.38	3.68
Minimum response time	2.79	2.69	2.90	3.68
Maximum response time	4.33	4.91	4.42	3.68
Minimum % busy	.05	.09	.05	.02
Maximum % busy	.20	.20	.24	.53

(Source: Rider [A-49])

possibly unique setting of New York City make it difficult to generalize from Rider's research. However, it appears additional research into the effect on the overall average of balancing the response in different areas of the jurisdiction could be fruitful.

A more intuitive, but often more complex mathematical procedure for dealing with extremes in response times is to impose constraints setting minimum service levels for each area. Instead of attempting to eliminate extremes by weighting in the criterion function, minimum levels are explicitly required.

Examples of such approaches are a minimal "protection" constraint imposed in Stacey [A-53] and a minimal "coverage" constraint that is part of the New York City-Rand Institute relocation procedure [A-29]. These constraint schemes are discussed in detail in the following chapter.

## 5.5 SUMMARY

Fire suppression resource allocation questions at the company level include "Where should suppression companies be positioned?"; "How should companies be repositioned during serious emergencies?"; and "What companies should be assigned to respond to particular alarms?" The first requirement for selecting among alternative plans for answering these questions is a criterion or objective function which quantitatively evaluates the alternatives.

The most important such criterion in fire research has been company response time. Among the implications of research to date are:

- Response time is a valid surrogate measure of fire loss.  
Both the size of the fire and the resources required to control it appear to increase with response time.
- Response time can be efficiently and accurately estimated from rectilinear distance, but a nonlinear time-distance relationship is required for short-distance responses.

The most important response time issue which has not been resolved in the research reviewed is the pattern (linear, exponential, etc.) of growth in fire losses with response time. Better understanding of this pattern of growth would indicate whether longer response times should

be given special weight in suppression allocation criteria.

Research on demand for fire suppression services is not nearly as advanced as that on response time. The research reviewed has been largely limited to:

- Documentation of significant time of day, day of week, and month of year variations in alarm rates; and
- Development of heuristic measures of fire seriousness.

In order for truly valid suppression resource allocation procedures to be developed, research apparently needs to be pursued on:

- Forecasting procedures to predict the alarm rate for different areas and times; and
- Objective measures of the seriousness of fire risk in a neighborhood which are relatively independent of the current locations of fire suppression forces.

Other suppression resource allocation criteria which have been proposed in the research reviewed include:

- Rating standards of the Insurance Service Office (ISO)
- Balance of suppression company workloads
- Response to nonstructure fire alarms
- Dollar cost to society.

However, little research was found which investigated either the relation between these measures and the overall objectives of the fire service, or the sensitivity of resource allocation to the measure. It appears (on the basis of the response of the Professionals Panel) that research is particularly needed on the role nonstructure fire alarms should play in resource allocation.

In addition to investigation of the validity of individual resource allocation criteria, some researchers have addressed the problem of aggregating criteria values for individual situations into overall, city-wide measures. The great majority of researchers have ultimately resolved this issue by employing a city-wide average response time (either with or without weighting for fire service demand) as the measure of value of a resource allocation plan. However, a number of limitations of this approach have been noted.

- It is not clear how response time for the several companies responding to the same alarm should be combined in an average response criterion;

- It may be possible to develop a weighting procedure that eliminates the undesirable extremes in response to individual neighborhoods which result from simply minimizing city-wide average response without seriously degrading the overall performance of the allocation plan.

Better investigation of these limitations would greatly enhance the value of resource allocation procedures employing average response time as a criterion.

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## CHAPTER 6

### SUPPRESSION RESOURCE ALLOCATION

As explained at the beginning of Chapter 5, suppression resource allocation concerns the positioning, repositioning, and assignment to fires of suppression forces and equipment.<sup>1</sup> Full investigation of policies for such suppression allocation includes decisions on the two questions "What is the proper composition of fire companies?" and "How should fire companies be allocated?" However, for simplicity, the first of these two questions is treated in Section 3.3 of this report, and discussion of suppression resource allocation in this chapter is limited to policies for allocating full companies.

There are, of course, many different questions or problems which might confront a fire protection official in deciding on allocation policies for his suppression companies. However, like all resource allocation problems, these fire protection questions always involve two separate components. The limitations on the range of alternative policies or decisions provide the constraints of the problem. Constraints may arise from geographic features, budget limitations, response requirements, political considerations, or a host of other possibilities.

In order to choose among alternatives which satisfy the constraints of a problem, however, a criterion or objective function is needed. Such a function makes possible the selection of the best or optimal policy from among all the feasible alternatives which satisfy the problem constraints.

As might be expected, the suppression resource allocation research review for this report exhibited much more uniformity of objective

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1. An excellent survey of research on the more general question of allocating urban emergency units can be found in Chaiken and Larson [6-12].

functions than of constraints. Problem situations--and thus the limitations on feasible solutions--vary widely in fire suppression resource allocation research, but the central objective of reducing fire loss remains fairly constant.

For this reason, research on criteria for fire suppression resource allocation is treated separately in Chapter 5 of this report. In the present chapter, discussion will focus on the actual problem situations and constraints addressed by suppression resource allocation researchers, with criteria used to select among alternatives being stated but not evaluated.

The following three sections address (1) the problem of positioning companies at "home base" facilities, (2) the problem of deciding the proper companies to assign to a particular alarm, and (3) the problem of repositioning companies when serious fires are in progress. A final section then reviews suppression resource allocation research which is not addressed to particular problems.

A continuing issue in the discussions of those sections is the validity of the assumptions made about the fire environment. For example, an assumption implicit in most of the research to be discussed below is that suppression response units are located separately in single unit facilities. Allocation plans designed under this assumption certainly include the cases of single-company facilities and facilities that house several units which always respond together. Unfortunately, few researchers have directly addressed the more realistic case where more than one company may be housed at each facility, but the mix of responding units for a particular alarm varies with the nature of the alarm.

As explained in Chapter 5, nearly all fire suppression resource allocation research has employed some measure of the response performance as the criterion for selecting among allocation plans. The most common such measure is average response time. In order to calculate this or other measures of response performance, the research discussed below often makes assumptions about the response. Nearly all the research assumes units are almost always called out from their fixed

locations. Thus, units are assumed almost never to be dispatched while they are in transit between alarms. It might be expected that this assumption would be valid in all jurisdictions except those with very high alarm rates. The Professionals Panel confirmed this belief by indicating that this assumption is consistent with the environment in most jurisdictions.

Some research also assumes the closest suppression unit almost always responds to an alarm. It is certainly the policy in most fire jurisdictions to assign the closest available unit, but that unit may not be the unit with the closest regular location. The Professionals Panel found the assumption that the "first choice" unit is almost always available fairly consistent with their experience; however, they were clearly more troubled by this assumption than the previous one.

Finally, the research varies in the manner in which response times are considered. Some assume that the response of the first responding unit is the only one of importance. Other work attempts to include the response of several units in the calculations. The Professionals Panel found the idea that the response of the first arriving unit is the only important one even more debatable than the previous assumption. Therefore, the simplification of considering only the first response time substantially weakens research where it is employed.

## 6.1 POSITIONING POLICIES

The problem of positioning fire suppression companies is the problem of deciding where to locate companies as a "home base" or at the beginning of a shift. It thus includes both the decision on where to locate the fire station from which a company will operate and where to position fire companies within the available stations.

Historically, the first thorough attempt to use systematic, scientific approaches in the development of a positioning policy was the work of Valinsky [A-58] in the early 1950's. This study developed a plan for the positioning of fire companies in New York City.

The analysis proceeded in four general steps. First, a set of positions was developed which satisfied the maximum response distance

criteria of The National Board of Fire Underwriters.<sup>1</sup> Second, a careful analysis of the burnable material in each part of the city was made in order to increase coverage in areas with higher risk. This analysis resulted in some shifting of company locations from the original plan.

The last two steps involved further refinement of the positioning plan on the basis of its ability to respond to short-term emergencies. The anticipated workload of each company position was first analyzed to determine if any area would be poorly covered because its nearest company was too often busy. Then, the performance of the proposed plan when major emergencies occupied many units was analyzed. Some additional adjustments in the plan were made on the basis of these last two steps.

While historically significant, the systematic, commonsense approach of Valinsky has been replaced more recently by more mathematical positioning approaches. This more recent research on positioning decisions can be classified with respect to the nature of the region which must be served. The three subsections which follow address this research in three general categories, each making different assumptions about the region. First the problem of positioning suppression units in a homogeneous region is addressed, i.e., the problem of positioning in a region where demands for service occur uniformly in all parts of the region. Any location in the region is just as likely to generate an alarm as any other location, and all alarms are of equal importance.

When there is substantial variation in the rate or the importance of alarms, the region becomes heterogeneous. The variations must be explicitly considered in formulating a positioning policy. The last two subsections of this section address this more difficult case--first when units are limited to a fixed set of positions in the region, and later when several units can be positioned at any point.

A decision on a positioning policy is necessarily a fairly permanent one. Thus, companies will be positioned in approximately the same way over fairly long periods of time. However, this does not imply that each region must have only one positioning plan. Several

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1. Now the Insurance Service Office (see Section 5.3.1).

different plans may be chosen, each to be implemented under different demand conditions. For example, it is common in some parts of the United States to have one positioning plan for the peak grass fire season and another for the remainder of the year.

When considering a positioning policy which includes several such positioning plans, a fire service decision-maker must, of course, consider the interactions between the plans. For example, fire stations cannot be repeatedly built and demolished as different seasons of the year arrive. However, the positioning research to be discussed in this section has generally ignored such interactions. Nearly all the research assumes particular positioning plans are to be designed separately, with interactions being dealt with by hand after the design procedure is complete.

#### 6.1.1 POSITIONING IN HOMOGENEOUS REGIONS

The most easily solved positioning problems arise in the case where the region to be protected is homogeneous, i.e., the rate and importance of alarms is equal throughout the region. However, it is probably unrealistic to believe any region exactly conforms to this definition. The Professionals Panel found debatable the idea that alarms are equally distributed over even the individual districts assigned to particular fire companies.

In spite of the questionable validity of the homogeneity assumption, a considerable body of research in many fields, including fire protection, has dealt with location problems in homogeneous regions. These apparently unrealistic problems have been considered worthy of serious attention because (1) they are often easy to deal with mathematically, and (2) empirical evidence has indicated results in more realistic situations are often effectively approximated by theoretical results from the homogeneous case. Thus, the importance of procedures developed to position facilities in a district with homogeneous demand arises more from interest in obtaining simple, approximate results than from a belief that homogeneous regions of any significant size actually exist.

The great majority of the fire systems research concerned with positioning in homogeneous regions has been performed by persons

connected with the New York City-Rand Institute. A series of research efforts by that organization has produced and validated a simple positioning approach. The Rand research is based on a mathematical model derived from the following assumptions and definitions:

- The region under consideration is square and has land area A
- The total number of suppression units to be assigned to the region is n
- Each unit is to be assigned a separate part of the area A, and answers all calls in the area
- Units travel about the area A over a rectangular grid of streets (i.e., according to the rectilinear<sup>1</sup> measure of distance)

Under these very strong assumptions, it can be shown mathematically that the arrangement of facilities and district boundaries which minimizes overall average response distance to alarms is the one shown in Figure 6-1. The districts of the optimal solution are square and at 45-degree angles with the direction of travel on the street network.<sup>2</sup> Each of the units is located at the center of its response district and average or expected response distance is given by the formula

$$\left( \begin{array}{c} \text{expected} \\ \text{distance} \end{array} \right) = \frac{2}{3} \sqrt{\frac{A}{n}} .$$

In the first of several papers by the Rand group, Kolesar and Blum [A-27] developed these simple results into a general concept that the average or expected response distance in an area could be expressed

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1. See Section 5.1.3 for further definition and discussion of rectilinear distance.
  2. This solution is also the motivation for the familiar "diamonds" method used for crude fire station location. If the above assumptions were met, a set of nonoverlapping diamonds of equal size which covered the region would be an optimal districting plan.

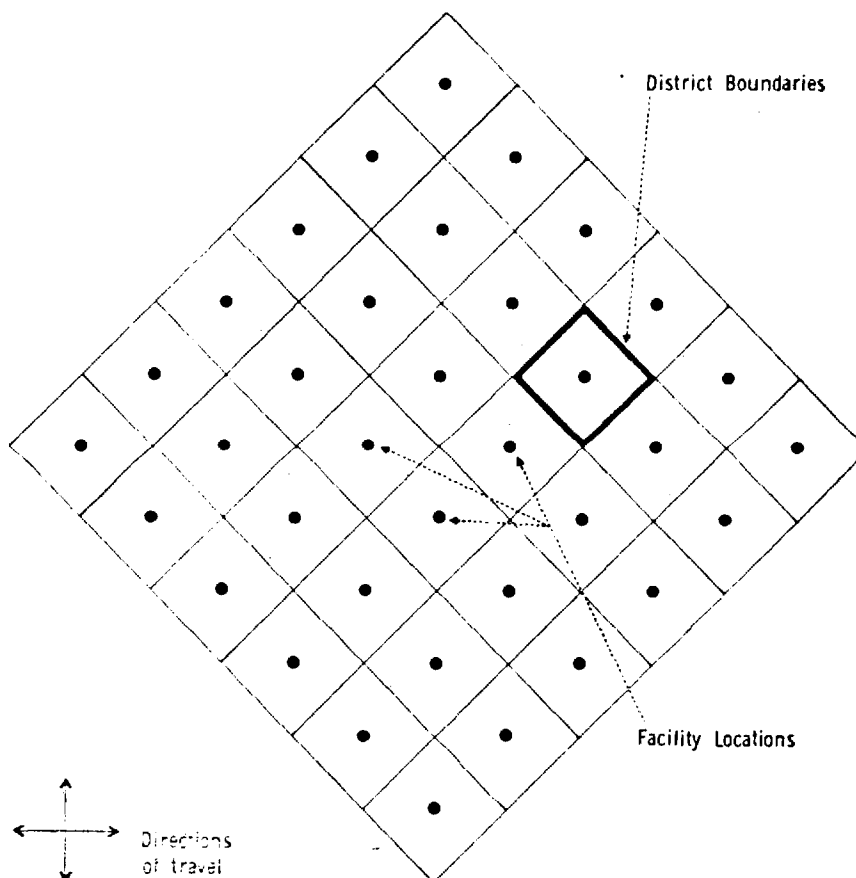


FIGURE 6-1. OPTIMAL FACILITY LOCATIONS IN  
A HETEROGENEOUS REGION

(Source: Larson and Stevenson [A-33])



by a version of the above formula with the number of units  $n$  replaced by the average or expected number of units available when an alarm arrives. The expected number of units available, in turn, can be calculated as the total number,  $n$ , minus the average number busy on calls. If

$\mu$  = the average time (in hours) required by a company to service an alarm and return to its usual position

$\lambda$  = the average number of alarms per hour,

the average number of units available can then be calculated<sup>1</sup> by the mathematical expression

$$(n - \lambda\mu) .$$

Kolesar and Blum thus argue that an approximate formula for the expected response distance associated with assigning  $n$  units to a region of area  $A$  can be given by

$$\left( \begin{array}{c} \text{expected} \\ \text{distance} \end{array} \right) = (\text{constant}) \sqrt{\frac{A}{n - \lambda\mu}} .$$

This expression gives only an approximate solution to even the above and similar simple mathematical situations discussed by the authors. However, an attempt was made to validate the formula under more realistic circumstances. New York City-R's computer simulation<sup>2</sup> of the Bronx area was used to generate a large number of hypothetical responses through actual neighborhoods to alarms which were not spread evenly over the region. One set of results from this validation is shown in Figure 6-2. That figure shows the average response

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1. Under the assumption that the occurrence of alarms is independent of the time to service alarms.
  2. See Section 6.4 for discussion of this simulation program.

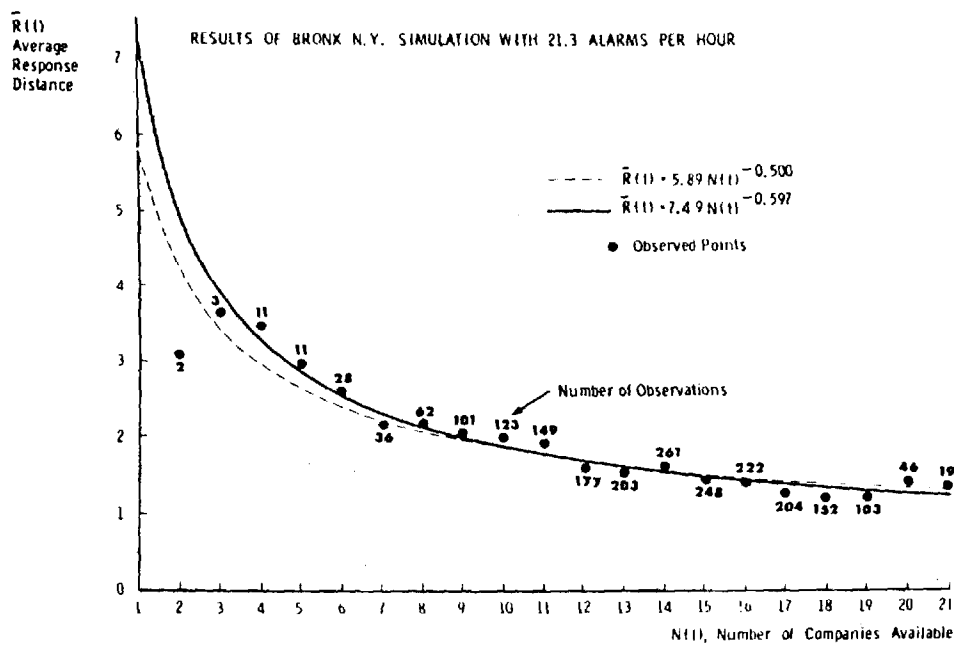


FIGURE 6-2. COMPARISON OF ESTIMATED AND SIMULATION RESPONSE DISTANCES BY NUMBER OF AVAILABLE COMPANIES  
(Source: Kolesar and Blum [A-27])

distance calculated in the simulation for different numbers of units available in the region. The results clearly conform fairly well to the dotted line which was obtained from a version of the above "square root formula."

In a set of related research performed by Kolesar and Walker [A-28] mathematical expressions for relating response distance and response time were investigated. A full evaluation of this research was presented in Section 5.1.3 of this report. However, the principal conclusion of the work can be stated simply. Response time appeared to grow with the square root of response distance for short distances (up to one or two miles) and then grow proportionately with distance for greater response distances. Thus, response time could be given by equations of the form

$$\left( \begin{array}{c} \text{response} \\ \text{time} \end{array} \right) = \begin{cases} (\text{constant}_1) \sqrt{\left( \begin{array}{c} \text{response} \\ \text{distance} \end{array} \right)} & ; \text{ if distance} \leq d \\ (\text{constant}_2) + (\text{constant}_3) \left( \begin{array}{c} \text{response} \\ \text{distance} \end{array} \right) & ; \text{ otherwise } . \end{cases}$$

In [A-26] Kolesar combined these results with the earlier expression for response distance derived in [A-27]. Under the assumption of a "square root" formula for expected response distance, and the above formula for response time in terms of response distance, he argued an approximate formula for response time could be given by

$$\left( \begin{array}{c} \text{expected} \\ \text{response} \\ \text{time} \end{array} \right) = \begin{cases} (\text{constant}_1) \sqrt[4]{\frac{A}{n - \lambda\mu}} & ; \text{ if } A \leq (\text{constant}_4) \\ (\text{constant}_2) + (\text{constant}_3) \sqrt{\frac{A}{n - \lambda\mu}} & ; \text{ otherwise } . \end{cases}$$

As in his earlier work with Blum, Kolesar attempted to empirically validate this estimating relationship by running a number of hypothetical cases with New York City-Rand's computer simulation. Since the simulation program itself employs estimation procedures not unlike the one being validated, it would be inappropriate to attach much significance to this validation effort. However, the results generally did

find that the above expression for expected response time in a district conforms closely to simulated situations where demand is not homogeneous.

Review of the above discussions will show that the estimating procedures so far discussed are not actually addressed to the question, "Where should units be positioned in a homogeneous district?" Instead they seek to answer the question, "What response time performance can be expected if  $n$  units are assigned to, and nearly optimally located within, a given district?" In preliminary comments in Kolesar and Blum [A-27], and in much more detail in Rider [A-49], this approach was extended to the question of "How should  $N$  units be divided among a set of homogeneous response regions to obtain the minimum average response time?" The simple square-root formulas are used to approximate expected response time in each region as part of a more complicated effort to divide a total number of response units among several regions. Each region was allowed to have a different alarm rate and "hazard factor," the latter indicating the nature of the property in the region. A weighting factor  $\beta$  was also used to control the variations in average response times for individual response districts.<sup>1</sup>

A mathematical statement of Rider's formulation and solution is given in Table 6-1. The optimal solution can be loosely summarized by the principle "allocate to each region a number of units equal to the sum of the average number busy ( $\lambda_i \mu$ ) and a portion of the remaining forces which increases with alarm rate, hazard, and area of the region." Though the number of units allocated to a region grows with the demand and size of the region, it does not grow proportionately. A region with twice as much demand as another will have less than twice the number of response units in the optimal solution.

Guild and Rollin [A-16] pursued a similar optimization approach in their work at Pennsylvania State University. These authors also drew on the square root relationship between average response distance and average area assigned to each of the  $n$  companies allocated to a homogeneous response region.

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1. See Section 5.4.4 for full discussion of this weighting approach.

TABLE 6-1. RIDER'S MODEL FOR DIVIDING COMPANIES AMONG SUBREGIONS

Formulation	
minimize	$\sum_i \lambda_i \left[ h_i c_1 \left( \frac{A_i}{n_i - \mu_i \lambda_i} \right)^{\frac{c_2}{2}} \right]^{\beta}$
s.t.	$\sum_i n_i = N$
where	<p><math>\lambda_i</math> = alarm rate in area i</p> <p><math>h_i</math> = hazard factor in area i</p> <p><math>A_i</math> = land area of area i</p> <p><math>n_i</math> = the number of units to be assigned to area i</p> <p><math>c_1, c_2</math> = constants associated with the response time estimating formula</p> <p><math>\beta</math> = the tradeoff parameter for controlling effects of extremes in performance in some areas</p>
Optimal Solution	
	$n_i = \lambda_i \mu_i + \lambda_i^2 h_i^{\nu\beta} A_i^{(1-\nu)} \left[ \sum_i \lambda_i^2 h_i^{\nu\beta} A_i^{(1-\nu)} \right]^{-1} \left[ N - \sum_i b_i \right]$
	where $\nu = \frac{2}{c_1\beta+2}$

(Source: Rider [A-49])

The principal difference in Guild and Rollin's work is the inclusion of economic considerations. Instead of merely minimizing expected response time, these authors attempted to state and minimize an expression for the overall cost to society of a fire suppression allocation program.<sup>1</sup> The expression was derived from the assumption that a unit responds to each alarm in its part of the region, whether or not it is available when the alarm arrives. Calls which arrive when the unit in the district is busy must wait for service until the unit becomes free.

Using this assumption, Guild and Rollin express the cost per fire to society when  $n$  units are assigned as

$$\left[ \begin{array}{l} \text{Expected cost per} \\ \text{fire of maintaining} \\ n \text{ companies} \end{array} \right] + \left[ \begin{array}{l} \text{Cost per} \\ \text{hour of} \\ \text{burning} \end{array} \right] \left[ \begin{array}{l} \text{Expected waiting} \\ \text{time due to wait-} \\ \text{ing for the pri-} \\ \text{mary unit} \end{array} \right] \\ + \left[ \begin{array}{l} \text{Expected travel} \\ \text{time to and from} \\ \text{the fire scene} \end{array} \right] + \left[ \begin{array}{l} \text{Expected service} \\ \text{time at the fire} \\ \text{scene} \end{array} \right]$$

Mathematical expressions for each of these quantities are given in the detailed formulation presented in Table 6-2.

Implicit in the expressions of Table 6-2 are the ideas that (1) response time is a simple multiple of response distance, (2) ultimate growth of a fire is not affected by response time, and that (3) the relative importance of costs for fire suppression forces and costs of fire losses can be expressly quantified. Each of these is a fairly severe assumption not justified by the corresponding discussions in Chapters 2 and 5 of this report. In addition, the assumption that an alarm must wait until its primary response unit becomes free is clearly consistent with reality only in a jurisdiction where very few of the units are busy at any particular time. Finally, the authors apparently attempted no validation of their approach as an approximation to actual

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1. See Section 5.3.4 for additional discussion of societal cost approaches.

TABLE 6-2. GUILD AND ROLLIN'S EXPRESSION FOR AVERAGE COST  
OF A GIVEN NUMBER OF UNITS

$$C(n) = \frac{C_f n}{\lambda} + C_v \left\{ \frac{\frac{\lambda}{n} \left[ \left[ \frac{A}{6nv^2} + \frac{1}{\mu^2} \right] + \left[ \frac{A}{nv^2} + \frac{1}{\mu^2} \right] \right]^2}{2 \left[ 1 - \frac{\lambda}{n} \left( \sqrt{\frac{A}{n} + \frac{1}{\mu}} \right) \right]} + \sqrt{\frac{A}{nv^2} + \frac{1}{\mu}} \right\}$$

where  $C(n)$  = cost per fire with  $n$  units assigned

$\mu$  = mean time spent at the fire scene

$\lambda$  = the average rate of alarms

$A$  = the land area of the region

$v$  = the average travel velocity of fire vehicles

$C_f$  = the average cost per hour of maintaining one company

$C_v$  = fire average cost per hour of uncontrolled burning at fire scenes

(Source: Guild and Rollin [A-16])

experience. Thus, the usefulness of this work as either an exact or an approximate decision-making procedure seems in doubt.

The potential value of any of the expressions derived under the assumption of homogeneous regions lies primarily in the degree to which the formulas provide adequate approximations in more realistic settings. Some additional information on the sensitivity of results to the strong underlying assumptions is offered by the work of Larson and Stevenson [A-33]. Under the assumptions of a homogeneous region, these researchers investigated the variations in expected response time resulting from nonoptimal positionings of response units.

Three separate analyses were performed. In the first, the optimal expected response distance derived from the solution of Figure 6-1 was compared to the expected response distance if units were dispersed randomly through the region. Optimally located units performed only about 25 percent better than randomly located units. Thus, if--as the Professionals Panel agreed--current positions of response units are "fairly good," only relatively small improvements could be expected by moving to mathematical optimal locations.

Larson and Stevenson's second and third analyses concerned two adjoining districts to be created from a single region. First, under the assumption that the districts did not cooperate, and later allowing cooperation, the researchers calculated the optimal location for the second facility given that a first had already been fixed.

The result of one of these analyses is presented in Figure 6-3. The range of locations tried for the first, or fixed facility is indicated by the circle at the bottom of the region. The corresponding variation in the optimal location for the second facility at the top of the region is clearly much smaller. Thus, the researchers concluded that exact optimality of the positions for response units is not necessary to achieve expected response times within 15-20 percent of the possible value.

Because of the severity of the assumption of homogeneous demand, it appears improper to draw from Larson and Stevenson's work the broad conclusion that positioning problems are all insensitive to deviations from optimality. However, the work does appear to give evidence for



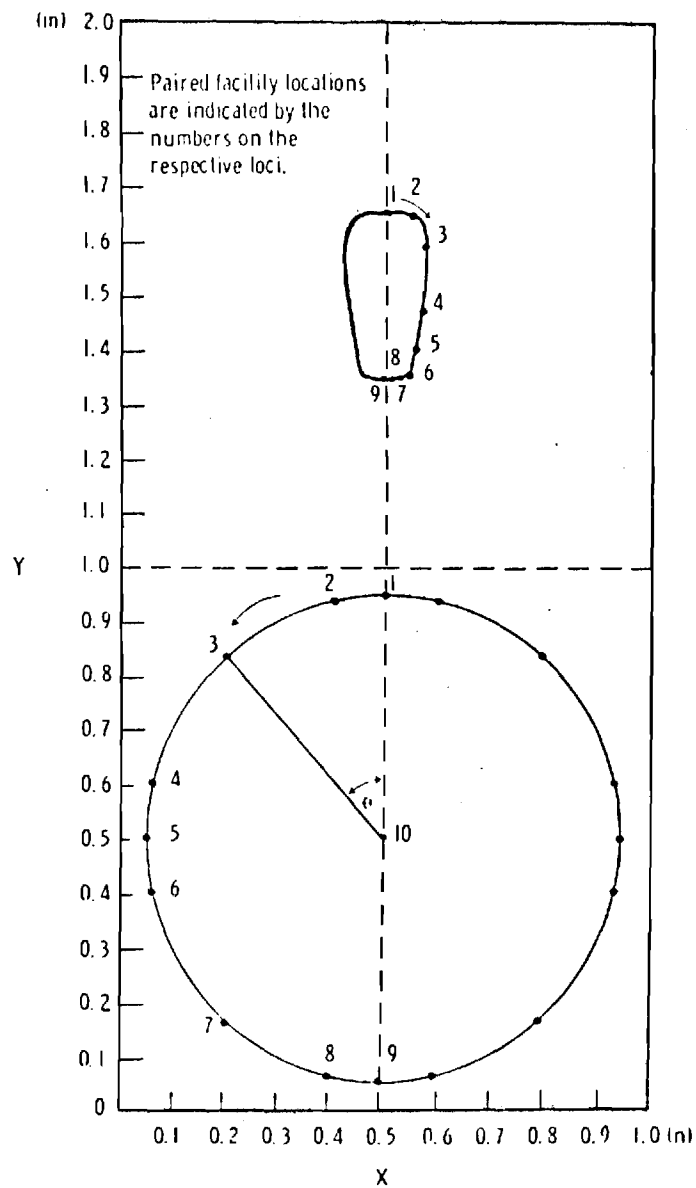


FIGURE 6-3. VARIATION IN OPTIMAL LOCATION WITH CHANGES IN POSITION OF FIXED UNIT  
(Source: Larson and Stevenson [A-33])

the general usefulness of approximate methods for calculating response times. Larson and Stevenson have demonstrated that the exact positioning of the units does not greatly affect the resulting expected response time. Thus, it seems that approximate formulas like the square-root ones discussed above could provide fairly satisfactory results when the objective is the selection of "essentially" optimal positions.

Taken together, all the above research on positioning in homogeneous regions appears to indicate that the simple "square-root" formulas derived from analysis of such regions may provide good approximations for many positioning problems. Much more empirical verification outside the (possibly very special) New York City setting would be required before the techniques would be clearly proved to be practical decision-making tools. However, it appears that these simple schemes are worthy of serious attention as tools for preliminary investigation of positioning plans.

#### 6.1.2 POSITIONING AT FIXED POSSIBLE LOCATIONS

When the region to be protected by a positioning plan has heterogeneous demand (i.e., variations in the rate and importance of alarms in different parts of the region), the positioning problem becomes significantly more difficult. Two possible problem situations are presented. In one case, the facilities can be placed almost anywhere. In the second case, the number of possible locations for the suppression companies is limited to a fixed set of candidates. Because of economic limitations, availability of land, political considerations, etc., only specific possibilities need be considered. The case with a fixed set of possibilities is addressed in this section, while the one with no limitations is pursued in the following section.

The most elementary problem of the fixed possibility type is to evaluate the response performance of a particular position in a pre-defined response district. Raouf's [A-47] study of Windsor, Canada, presented an approach for this case. Using historical information about the rate and seriousness of fire alarms in the district, Raouf calculated the value of a location as the weighted sum of the rectilinear distances from the location to the points where fires had

occurred. Weights were provided by the number of man-hours spent fighting the fire.<sup>1</sup>

Raouf proposed this solution merely as a method for periodically checking the locations of suppression forces. However, when possible locations and districts are generated externally by fire protection officials, the same principle could be used to develop districts.

Santone and Berlin's [A-51, A-52] study of East Lansing, Michigan, adopted just such an approach. Candidate districts and corresponding fire station locations were developed by hand on the basis of suggestions by fire protection officials. Each district then was evaluated by calculating the weighted average response time. In contrast to Raouf's simple analysis of rectilinear distance, response times in East Lansing were calculated by determining the shortest time path through a computer representation of the city's street network. Weights for the average were determined by subjective assessment of the hazard at each intersection or node of the traffic network.

These two studies demonstrate that relatively simple computational procedures can be devised to evaluate given positioning plans. Note, however, that two important assumptions have been made in this evaluation.

- (1) It is assumed that all demand in the heterogeneous district can be collected at a (possibly rather large) set of fixed points. Thus, for example, Santone and Berlin assumed all demand occurred at one of the nodes in their traffic network.
- (2) Perhaps more seriously, it is assumed that units should be positioned to reduce the average response time from the nearest unit location, whether or not that unit will actually be available at the time of an alarm. Plans are considered "good" if they minimize the response time from typical fires to the nearest unit location.

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1. See Section 5.2.2 for discussion of the limitations of this criterion.

If the number of nodes associated with (1) is sufficiently large, it would seem that assumption would not be particularly troublesome. Even though the Professionals Panel found the idea that a substantial majority of fire calls in an area are answered by the nearest company location fairly consistent with their experience, however, assumption (2) would seem to be a greater concern. Certainly the nearest unit would often be unavailable in busy jurisdictions like New York City.

If a decision maker is willing to accept at least assumption (1) above, it is possible to go beyond the approaches of Raouf, and Santone and Berlin to the point of allowing a computer procedure to design new districts. Two strategies have been proposed in the literature reviewed for this report. All begin with a list of possible positions, a list (possibly identical to the list of positions) of demand nodes which must be serviced, and a table indicating which nodes can be serviced from which candidate positions.

The table is created from the characteristics of the region studied. For example, the response time between all candidate locations and demand nodes may be calculated and runs which require too much time excluded. Similarly, if physical barriers (e.g., rivers) cross the region, locations on one side of the barrier can be excluded from servicing demands on the other side.

Jane Hogg of the British Home Office has made a number of studies using such an approach. In the first of these, [A-21], stations were determined for Glasgow, Scotland, as it is expected to look after extensive urban renewal in the 1980's. Travel times through the street pattern of the rebuilt Glasgow were estimated and the districts selected which minimized overall average response distance given a particular number of companies to be positioned.

Hogg's study of Bristol, England [A-22] followed a similar procedure. Again, districts and positions were selected for each possible number of suppression companies.

In both these studies, the author imposed one additional consideration not found in most of the other research surveyed for this report. The possible station locations were assumed to have a fixed number of bays, and companies were required to be located in one of the available

station bays. Thus, the "single unit positioning" assumption discussed at the beginning of this chapter was not required in Hogg's work.

In her master's thesis [A-20] for Glasgow, and later for Peterbrough and Market Deeping [A-23], Hogg used a slightly more complex positioning scheme. Constraints of the problem were similar to those of the earlier studies, but the criteria function was different. An attempt was made to minimize the cost to society of a districting plan by estimating the fire loss to be anticipated with a given response pattern and the cost of providing the fire company locations. The relation between response patterns and fire loss used to make such estimations was derived from a mathematical model of fire spread presented in [6-18].<sup>1</sup> The author reports that including these economic considerations in developing the districting plan produced results superior to those obtained by merely minimizing average response time.

In their study of Alexandria, Virginia Nilsson and Swartz [A-41] experimented with a districting scheme similar to Hogg's earlier work. A fixed, desired number of positions was determined, and that number of districts designed in a way which minimized the average distance between demand nodes and the nearest unit location. However, capacity of potential fire station locations was not included, as it had been in Hogg's work.

In [A-65] the Metropolitan Dade County Florida Fire Department describes an extension of Santone and Berlin's [A-51, A-52] approach, presently used to locate fire stations in the Miami area. This procedure begins with (1) an indication of which current stations cannot be moved, (2) a number of new stations to be located and a set of initial positions for these stations, (3) the frequency of alarms in each subregion of the county, (4) a table of the lengths of the shortest travel-time paths between all major intersections in the county through a computerized representation of the actual street

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1. Research of such fire spread models is beyond the scope of this report. However, Section 5.1.1 discusses some of the data on which this procedure was based.

pattern, and (5) a list of the "desired travel times" calculated for each subregion on the basis of the size and land use in the subregion. The procedure then attempts to improve on the initial set of locations for the "movable" stations. Improvements are measured in terms of reducing the overall "exposure" of the region, i.e., the sum of the products of the frequency of alarms in each subregion and the percentage by which the actual travel time from the subregion to the nearest station fails to meet the desired travel time criterion.<sup>1</sup> Station locations are restricted to the intersections in the traffic network representation.

Another study identified for this report which used the concept of covering fixed locations is the work of Mitchell [A-39, A-40]. This author developed an approach and applied it in Fullerton, California. Like most of the other studies described above, Mitchell divided the region into a set of demand districts or nodes, selected a number of units to be positioned, and then designed districts which minimized overall average response time to the pattern of alarms which had been experienced in the region. A number of other limitations, such as a maximum possible expenditure for suppression services, were discussed, but none was actually employed in the districting procedure.

The important characteristic of Mitchell's work which distinguishes it from the other studies discussed above was his attempt to include the response of more than one company in the overall average being minimized. At each demand point, he calculated the response performance of a given plan as the response time from the closest position in the plan plus the response time of the second closest, weighted by the chances that a second unit would be needed in alarms at that demand point.<sup>2</sup> The chances of a second unit being needed was estimated from

- 
1. See Section 5.2.2.1 for further discussion on the exposure measure.
  2. Mathematically this objective function is given by

$$\min_{A_k} \sum_j p(j) \left[ \min_{i \in A_k} d(i,j) + q(j) \min_{\substack{i' \in A_k \\ i' \neq i}} d(i',j) \right]$$

(Continued p. 222)

the history of alarms at that location.

A final formulation of the fixed location type is the one applied by Stacey [A-53] in Dayton, Ohio (see Table 6-3). Like the authors above, Stacey modeled the positioning problem as one of allocating a given number of companies over possible locations in a way which would maximize the service to a set of demand points. However, positioning plans also were constrained to provide given levels of "protection" to each demand point, and fit within limits on available company bays at the locations where units could be positioned. A set of dimensionless measures of the seriousness of risk, each weighted by the reciprocal of response distance, provided the indices of "protection" used in these constraints,<sup>1</sup> and the procedure sought to maximize total protection.

This formulation embodies many of the constraints of the other approaches discussed above. Like Hogg's work, the formulation accounts for combining companies into station locations with limited numbers of bays; like the Dade County approach, consideration is given to a desired level of protection to each demand point; and like Mitchell's formulation, some weight is given to the protection offered by units other than the closest to each demand point.

The principal difficulties with Stacey's formulation are the complication that optimal solutions may very well require fractional numbers of companies at some locations and the complexity of implementing the "protection" constraint concept. Unless some suitable interpretation of say 2.6 companies at location  $i$  can be made, the fractional solutions which may be produced by Stacey's approach would

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where  $A_k$  = any set of  $k$  possible positions

$p(j)$  = the probability of a given alarm coming from demand point  $j$

$q(j)$  = the probability an alarm at demand point  $j$  will require multiple companies

$d(i,j)$  = the estimated response times from position  $i$  to demand zone  $j$ .

1. See Sections 5.2.2.1 and 5.4.1 for further discussion of these protection measures.

TABLE 6-3. STACEY'S FORMULATION OF THE POSITIONING PROBLEM

Maximize:

$$\sum_i \sum_j p_{ij} x_j$$

s.t.

$$\sum_j x_j \leq d$$

$$\sum_j p_{ij} x_j \geq C_i \quad \text{for all } i$$

$$b_j^1 \leq x_j \leq b_j^2 \quad \text{for all } j$$

where  $x_j$  = the number of units assigned to station  $j$

$b_j^1$  = the minimum number of units which can be assigned to station  $j$

$b_j^2$  = the maximum number of units which can be assigned to station  $j$

$d$  = the total number of companies available

$p_{ij}$  = a dimensionless measure of the protection afforded demand point  $i$  by a company at station  $j$  (inversely proportional to the travel distance from  $i$  to  $j$ )

$C_i$  = the minimum level of protection acceptable at demand point  $i$



have to be rounded to yield a meaningful positioning plan. Rounding may destroy the optimality of the positioning plan. More importantly, the dimensionless nature of Stacey's protection measures makes it very difficult to specify the requirements  $C_1$ . The  $C_1$  do not correspond directly to any measurable quantities in the fire environment.

Though producing some difficulty in converting a mathematically optimal solution into a reasonable positioning plan, Stacey's formulation has the advantage that it can be solved relatively efficiently. The formulation is of the type referred to by operation researchers as linear programs, and several well-known and efficient solution procedures are available.

Problems like the ones formulated in all the above studies except Stacey's are termed set covering problems in the literature of operations research. Such problems occur in many facility location problems like those found in fire suppression positioning. Thus, additional research and information on such approaches can be found in the more general works of ReVelle, Marks, and Liebman [6-28]; Toregas, Swain, ReVelle, and Bergman [6-38]; and in the excellent survey of these works in the fire context given in Colmer and Gilsinn [6-13].

Unfortunately, when any set covering procedure is to be used in identifying districts for a region, both the accuracy of the assumptions underlying the constraints of the procedure and the efficiency of the techniques to be used in obtaining a solution must be considered. It is, of course, possible to construct a very complex set of constraints which closely approximates the true fire service environment. However, solution of set covering problems is generally quite difficult, and complex formulations cannot be exactly solved by any known means.

The Hogg studies described above used a solution procedure which is exact, i.e., produces solutions which are certain to be truly optimal. All other authors used heuristic procedures, i.e., schemes which hopefully produce good approximate solutions, but which may not yield a truly optimal positioning plan.

Naturally, an exact procedure is to be preferred to a heuristic one when it can be employed efficiently. Unfortunately, however, the

complexity of the problems addressed by the above authors grows very rapidly with the number of candidate positions and the number of demand points. When these numbers become even moderately large, exact procedures become impractical. None of Hogg's studies, for example, included more than about 50 demand points.

Fortunately, there has developed in the field of operations research a large variety of heuristic set covering procedures which are known to give nearly optimal solutions in almost all cases. Nilsson and Swartz, as well as Mitchell, reported good results with the procedures they employed. Several other satisfactory schemes are outlined in the survey by Colmer and Gilsinn [6-13]. Perhaps most important of all, Hogg in [A-20] suggests that heuristic procedures would have produced almost as good results as those of her exact scheme, and would have required far less computation time.

#### 6.1.3 POSITIONING WHEN ALL LOCATIONS ARE POSSIBLE

In any real positioning decision process, it is probably true that the alternative positions are limited. Street patterns, land values, existing fire stations, etc., will restrict the number of feasible plans. However, if the number of alternatives is not too severely restricted, very good approximate positions may be obtained by treating the positioning decision as if a unit could be placed anywhere within the region. The results for homogeneous regions discussed in Section 6.1.1 are an example of just such useful approximations.

In this section, the research identified for this report which takes such a continuous approach to positioning in heterogeneous regions will be discussed. The number of researchers who have pursued continuous approaches in fire suppression positioning is much smaller than the number who have used the fixed location or discrete techniques of the previous section. However, some very powerful results have been derived.

Carter, Chaiken, and Ignall's [A-5] study of dividing a region into two response districts is one interesting example of this type. These authors sought to investigate the optimal choice of a boundary line between response districts assigned to two cooperating units. A

call arising in one district is assumed to be served by the unit in that district if it is available, by the other unit if the "first choice" unit is unavailable, and by some outside forces if both units in the region happen to be busy. Alarms in different parts of the region are all assumed to occur according to the Poisson probability distribution,<sup>1</sup> but the average density of alarms varies in different parts of the region. In addition, alarms occurring in the region were assumed to have a known distribution of times for units to "service" the alarms, i.e., travel to, suppress, and return from the fire scene. This service distribution was assumed unrelated to the distribution of alarms, so that, for example, the chances of an alarm requiring 30 minutes to service were unaffected by the location of the alarm or the response unit servicing it. Finally, response time was assumed to be proportional to rectilinear distance.

As the authors observe, these assumptions are rather severe -- particularly the one requiring service times, which include response times, to be independent of the location of the alarm and the unit providing service. However, the authors were able to obtain some instructive results under their assumptions.

A mathematical statement of the optimal division of the region into districts 1 and 2 is given in Table 6-4. Loosely, it states that the boundary which minimizes average response time will fall closer to the one of the two stations with the greater alarm activity. Thus, in many cases, the optimal solution is not, as is the common practice in modern fire departments, to establish a boundary which assigns each point in the region to the nearest station. In cases where the chances are not negligible that the nearest unit will be busy when an alarm arrives, these researchers have shown that a policy of sending a slightly more distant unit from a less busy region may be preferable in terms of reducing the overall average response.

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1. This distribution assumes calls arise randomly over time at a uniform density. See Section 5.2.1 for discussion of its validity in fire alarm analysis.

TABLE 6-4. EXPRESSION FOR THE OPTIMAL BOUNDARY BETWEEN DISTRICTS  
FOR TWO UNITS

$\lambda$  = mean alarm rate in the entire region

$\mu$  = mean service time for each alarm

$t_i(x)$  = response time to an alarm at point  $x$  from company location  $i$

$T_i$  = mean response time if all alarms were serviced by company  $i$

Optimal Boundary:

Any boundary which assigns to unit 1

all locations  $x \in \{x: t_1(x) - t_2(x) < s\}$

and to unit 2

all locations  $x \in \{x: t_1(x) - t_2(x) > s\}$

where  $s = \left( \frac{\lambda}{\lambda + \mu} \right) (T_1 - T_2)$

An interesting consequence of this result is that such a policy also tends to equalize the workload of neighboring fire companies.<sup>1</sup> Thus, under the assumptions made by these authors, it may be possible to design district boundaries which not only reduce average response time, but also equalize workload among suppression companies.

Since they contradict the common practice in almost every current fire jurisdiction, it is not surprising that the Professionals Panel doubted the usefulness of Carter, Chaiken, and Ignall's results. The authors themselves observe that the assumption that service times are independent of the alarm rates may lead to misleading results. In some simple cases where this assumption could be relaxed, results indicate that a boundary line closer to the "equal response time from the two units" line is optimal. Thus, while Carter, Chaiken, and Ignall's results place in doubt some of the standard positioning practices of modern fire departments (and, thus, most of the fixed location procedures of the previous section, which were based on response by the nearest unit), considerably more research would be required to prove or disprove the value of their results.

A second set of research on positioning in continuous, heterogeneous regions is the work of Chaiken [A-11]. Under the assumptions that alarms occur over a region according to the Poisson probability distribution (with different alarm densities for different parts of the region) and some very broad properties of the time required by fire suppression units at the scene of an alarm, this paper develops a mathematical expression for the distribution of the number of busy units in the region.

Mathematical expressions for this distribution are given in Table 6-5. To apply the formulas it is necessary to know

- the alarm rates in different parts of the region
- the distribution of times one unit, two units, three units, etc., spend at fire scenes.

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1. See Section 5.3.2 for discussion of the use of workload balance as a criterion for suppression resource allocation.

TABLE 6-5. CHAIKEN'S DISTRIBUTION OF THE NUMBER OF UNITS BUSY

Alarms of Type i:

Arise as independent Poisson process with rate  $\lambda_1$

Service of Type i Alarms:

- o Maximum number of units assigned is  $n_1$
- o Service occurs in  $2n_1 - 1$  independent stages characterized by the number of units assigned during the stage
- o Times in each stage  $j$  have arbitrary distribution with finite mean  $T_i(j)$
- o Total number of units is infinite

Steady-state Probability of  $m$  Units Busy:

$$P(0) = e^{-r}$$

$$P(m) = e^{-r} \left[ \rho(m) + \frac{1}{2!} \rho^{*2}(m) + \dots + \frac{1}{m!} \rho^{*m}(m) \right]$$

for  $m > 0$  and  $*k$  denotes  $k$ -fold convolution

$$\text{where } \rho(j) = \sum_i \rho_i(j)$$

$$r = \sum_j \rho(j)$$

$$\rho_i(j) = \begin{cases} \lambda_i \left[ T_i(j) + T_i(2n_1 - j) \right] & \text{for } j=1, \dots, n_1-1 \\ \lambda_i T_i(n_1) & \text{for } j=n_1 \\ 0 & \text{otherwise} \end{cases}$$

From these data, the entire probability distribution of the number of busy units in the region can be determined. Thus, for example, it is possible to assess the probability that 10, 20, 30, etc., companies would be simultaneously busy.

Like the research above, these results are subject to some mathematical cautions. First, they also assume that the distribution of times spent servicing an alarm are independent of the location of the alarm and the initial positions of the responding units. Under normal conditions, this assumption probably would be quite valid, but as a large number of units become occupied, travel times to the alarm sites would be likely to increase.

The author also requires the assumption that there are essentially an unlimited number of suppression companies in a region. However, considering mutual aid agreements, etc., this assumption does not seem limiting. Moreover, the Professionals Panel did find it fairly consistent with their experience.

One application made of these results is part of the work of Nilsson and Swartz [A-41] in Alexandria, Virginia. These authors used Chaiken's formulas to perform an "availability analysis" of the likelihood that given numbers of companies would be busy.

A less direct use of the Chaiken results is made in the work of Fitzsimmons [A-13, A-14] on allocation of ambulances to fire stations. This author developed a computer procedure for selecting positions for ambulances in a continuous region which minimized average response time. The technique works by calculating the average response time given a set of positions and a set of busy units through the use of a simple computer simulation. The probability that this particular set of busy units could occur then is calculated from Chaiken's results. Using Chaiken's probability as a weight for the response times with different numbers of busy units, Fitzsimmons was able to estimate the response performance of a particular set of locations. A systematic search technique then was employed to find the optimal locations.

Since Fitzsimmon's object was to locate ambulances at fixed stations, it would seem his assumption that the ambulances could be placed at any point in the region is quite limiting. However, in the

broader problem of positioning fire companies over a jurisdiction, the Fitzsimmons technique might be very successful. By eliminating the need for all of the assumptions about availability of the closest unit which were made in the other research presented above, this work would seem to give a very close representation of the actual positioning environment. Moreover, the computational procedure proposed could be expected to obtain optimal positions within a reasonable amount of computation time.

## 6.2 DISPATCH POLICIES

In the previous section, the question of selection of "home base" or primary positions for suppression companies was discussed. Such positioning elements of the problem of suppression resource allocation have received by far the greatest attention in the research surveyed for this report.

A complete policy for allocation of fire suppression forces, however, requires not only a set of more-or-less permanent positions, but plans for repositioning of units during serious fires, and rules for assigning units to respond to particular fire alarms. In the present and following sections, these temporal or situational policy questions are discussed.

In order to fully describe a dispatch policy, i.e., a policy for assigning available companies to incoming alarms, two specific questions must be answered for each type of alarm which might be received: "How many of each type of company should be dispatched in the initial response to the alarm?" and "Which of the available units should be assigned to obtain the desired numbers of companies?" Thus, it is necessary to determine both the level of response required and the specific units to make the response. In the following subsections, research on each of these questions is presented.

### 6.2.1 HOW MANY TO DISPATCH?

The first element of a policy for dispatching fire suppression companies to an alarm is a plan designating how many of each type of company to dispatch to various types of alarms. If too many units



are dispatched, suppression forces will be left in a poor position to respond to subsequent alarms. If too few are dispatched, additional injuries and loss may be incurred before adequate forces can be brought to the scene of the alarm.

The majority of modern fire jurisdictions deal with the question of "How many to send?" by establishing fixed responses for various types of alarms. For example, two engine and one ladder company might always be assigned the first response to a reported fire in an apartment building. This same number of companies would be assigned as the first response to such an alarm, regardless of the number of units which may be committed to other fires, etc. When the senior officer with the first responding forces determines that the initially dispatched forces will be inadequate, a second or higher alarm is called in and additional units are dispatched. This process may be repeated until third, fourth, and higher alarms have been filed, and additional units are dispatched.

In [A-43] Ottoson proposed a simple technique for dealing with the question of "How many to send?" in the context of such a scheme of incremental alarms. He argues that a dispatch policy should be arranged so that the risk that units dispatched on a given alarm will not be adequate to deal with a fire is equal for all such alarms. Thus, if 5 percent of first alarms require a second alarm, 5 percent of second alarms should require a third alarm, and so on.

Ottoson demonstrates that this approach easily can be applied in even the smallest fire jurisdictions. It is only necessary to record the number of fires ultimately requiring one, two, three, etc. engines over some substantial period of time. If the risk of needing reinforcements is to be set at 5 percent, the policy implied by these data is then to send a number of units selected so that the fraction of all alarms requiring more than that number of engines is 5 percent. The author suggests such a policy usually will result in smaller initial responses and larger second and higher alarm contingents.

Though simple and perhaps instructive for very small cities, Ottoson's proposal is subject to a number of limitations. First, the Professionals Panel found debatable the principle that the risk of

needing additional forces should be the same for all alarms. Apparently, the risk of denuding the jurisdiction of unassigned forces when a high alarm is sounded is sufficient to suggest some caution in sending the larger forces Ottoson's approach would imply. In addition, the method Ottoson proposed for calculating an appropriate policy is subject to the assumption that fire size is related only to the number of forces dispatched to an alarm, and not to the pattern by which they are dispatched. Certainly, if very few units are sent on the first response, then the chances of a multiple-alarm fire are greater.

A much more complex type of dispatch policy is the "flexible response" approach studied extensively by the New York City-Rand Institute. In such an approach, the number of units to be dispatched to an alarm depends on a number of elements which change as units become busy. Specifically, the Rand work has considered the following elements:

- (1) The probability that an alarm is serious, i.e., the likelihood that the alarm will require more than a minimal, one-company response
- (2) The number of units available in the surrounding area at the time the alarm is received
- (3) The relative weight or value attached to the response time of the first-arriving versus the second-arriving unit
- (4) The rate of alarms in the area surrounding the location of the alarm

The principal work on the Rand approach is presented in Swersey [A-55]. In that study, the essential problem is described as one of deciding between rapid response of the closest unit and rapid response of the second-arriving unit. Larger numbers of units also are discussed, but the issues are the same for the one versus two decision. In the case of two units, if only one unit is dispatched to a fire, the arrival time of the second (when it is needed) is delayed by the time for the first unit to reach the fire scene and request help. Thus, first response is relatively rapid, but second response is delayed. On the other hand, if two units are dispatched initially, the response time of the second unit is reduced, but a price is paid

in first response. A second unit which is not needed at the fire scene is out of service for the time required to reach and return from the fire scene. Thus, fewer units in the area are available for new alarms, and the average response time for first responding units will be correspondingly larger.

In [A-55] Swersey develops mathematical expressions which embody this tradeoff between first and second response times. Under various assumptions and simplifications, the implied dispatch policy is calculated.

After investigation of a number of possibilities, Swersey concludes that the most convenient dispatch rule is the one given in Table 6-6. Simply stated, this rule provides that the decision on whether to send one or two units should be based on whether the probability,  $s$ , that a given alarm is serious is greater than or equal to a calculated threshold, or criterion value. If  $s$  is larger than the calculated value, two units should be sent. Otherwise, one unit should be sent.

The criterion value, in turn, depends on the factors (1) through (4) given above. As the number of units busy in a region increases, or the alarm rate (i.e., chances of more alarms in the immediate future) becomes larger, the rule tends to dispatch fewer companies. As the anticipated seriousness of the alarm or the weight placed on the arrival of the second unit increases relative to the response of the first unit, the rule tends to dispatch more companies immediately.

Criterion values for different levels of these parameters in a region with fourteen total companies are shown in Figure 6-4. When the probability that an alarm is serious falls above the appropriate line in that figure, Swersey's rule calls for sending two companies. Otherwise, one company is sent on the initial dispatch.

In [A-10] Carter and Swersey investigated a slightly modified version of this decision rule by simulating different dispatch policies in the Rand computer simulation.<sup>1</sup> The environment simulated was the South Bronx, which experiences a relatively high alarm rate.

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1. See a discussion of the computer simulation in Section 6.4.

TABLE 6-6. SWERSEY'S FULE FOR HOW MANY TO DISPATCH

Criterion:

$$s^* = \frac{1}{2} (\min \{1, s_u\} + \min \{1, s_\ell\}) + w$$

where

$w$  = a workload factor ( $0 \leq w \leq 1$ )

$$s_u = \lambda \left\{ \frac{\alpha}{1-\alpha} \Delta T_{1/2} + \Delta T_{2/2} + \Delta T_{\min/2} \right\} \bar{s}$$

$$s_\ell = \lambda \left\{ \frac{\alpha}{1-\alpha} \Delta T_{1/1} + \Delta T_{2/1} \right\} \bar{s}$$

$\lambda$  = alarm rate in the region around the present alarm site

$\alpha$  = the weight attached to the response of the first unit as compared to the second

$\bar{s}$  = the expected probability of a serious alarm in the region around the present alarm site

$\Delta T_{i/k}$  = the estimated increase in the response time of  $i$ th units caused by dispatching a second unit to the present alarm when the number busy is assumed equal to the expected number when  $k$  units are always dispatched

$\Delta T_{\min/k}$  = the estimated increase in the response time of the closest unit caused by dispatching a second unit to the present alarm when the number busy is assumed equal to the expected number when  $k$  units are always dispatched

Policy:

Send 2 when  $s \geq s^*$

Send 1 otherwise

where  $s$  = the probability the present alarm signals a serious fire.

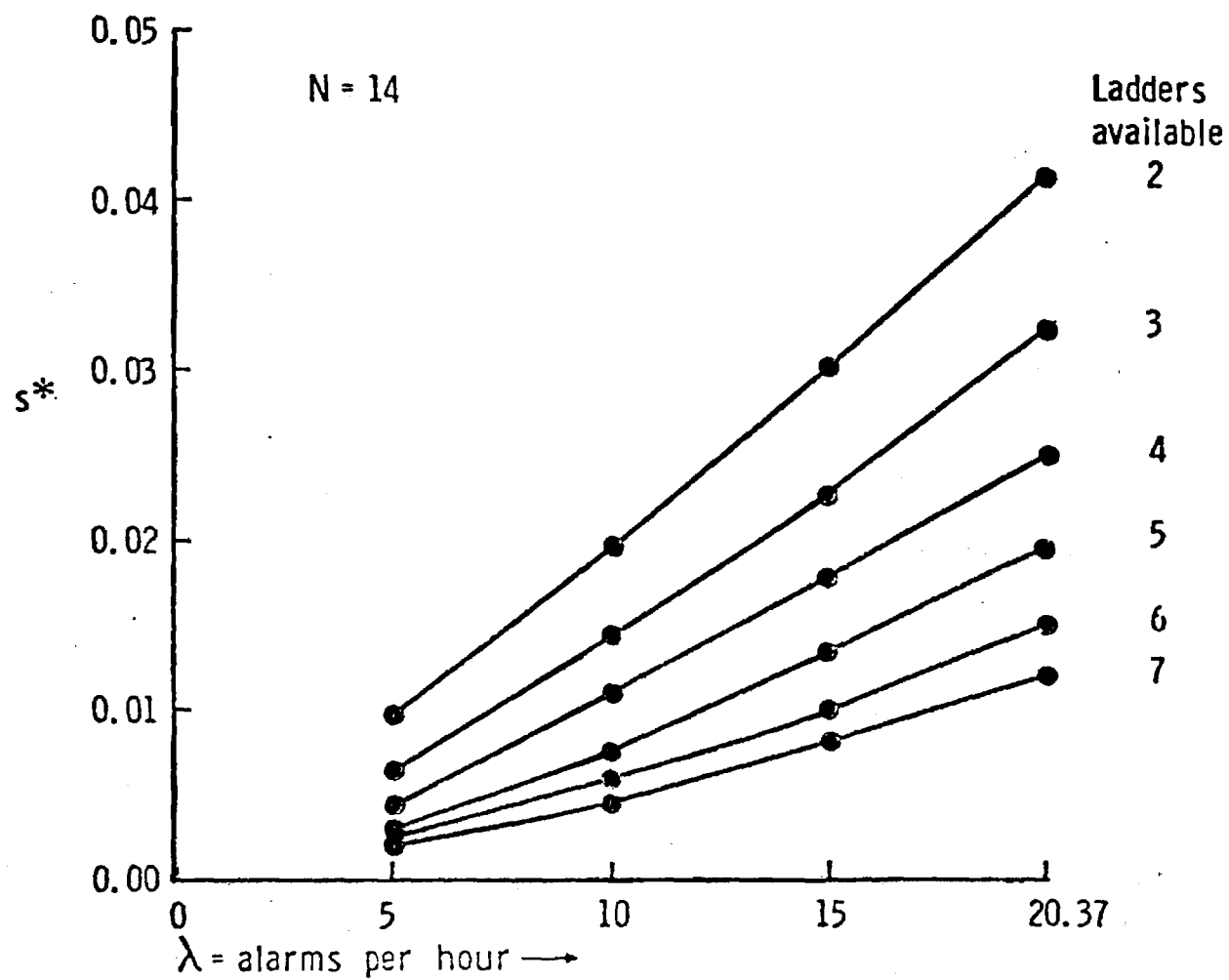


FIGURE 6-4. "SEND TWO" CRITERION VALUES BY ALARM RATE AND NUMBER BUSY

(Source: Swersey [A-55])

These simulation experiments generally supported the value of considering the availability of response units in a flexible dispatch rule instead of being restricted to a fixed dispatch policy. However, the greatest gain appears to have been derived from explicit investigation of the probability that an alarm signals a serious fire. By ruling out multiple response to alarms that are almost certainly not serious, the dispatch rule measurably increases the availability of fire companies.

Since the probability that an alarm is serious forms such an important part of their proposed dispatch rules, the Rand researchers also have performed considerable research on the prediction of this probability. In [A-8] Carter and Rolph performed an extensive statistical analysis which compared formulas for forecasting the probability that an alarm is serious. Generally, their experience with New York City data showed that the seriousness of an alarm could be determined quite accurately from the calling citizen if the alarm was reported by telephone. For alarms entered through alarm boxes, however, statistical procedures are required. Significant variations were observed in the seriousness of alarms from boxes only a few blocks apart, and at different times of the day and year for the same box.

Four different types of statistical approaches were considered. They included combinations of:

- (1) Direct estimation from the historical pattern at a particular alarm box, as opposed to partial attention to the historical pattern of boxes in the immediate area
- (2) Estimation of the probability an alarm is serious directly, as opposed to first estimating the probability an alarm implies a fire in an occupied structure and multiplying this probability by the chances that an alarm in an occupied structure is serious

Results of this analysis tended to support the approach which considers history of both the particular box and the surrounding area in predicting whether an alarm is serious. Moreover, though the difference is somewhat smaller, there is some advantage in estimating the chances that an alarm is serious in the two steps outlined in (2) above.

The researchers also found that variations for season and time of day must be considered to obtain an effective estimate of the probability that an alarm is serious. Thus, the procedure ultimately recommended includes:

- The history of alarms involving fires in occupied buildings at the particular alarm box
- The history of alarms involving fires in occupied buildings at surrounding boxes
- The historical chances that a fire in an occupied building is a serious fire
- The season of the year when the alarm is received
- The time of day when the alarm is received

While generally sound methodologically, the usefulness of Rand flexible response approach to the question of "How many to dispatch?" appears to depend on the degree to which availability of responding units is a problem in the particular fire jurisdiction. The Professionals Panel did generally agree that the alarm rate in the area of an alarm and the number of units currently available should be considered in developing rules for dispatching. However, it would appear that the effects of these factors would diminish if most units are available most of the time. For example, the criterion values shown in Figure 6-4 are all very close to zero unless at least half of the fourteen companies in the region are busy. Thus, the "How many to dispatch?" question would be complex enough to require the flexible response techniques developed by Rand only in areas with relatively high workloads.

The part of the Rand work which would appear to have wider application is the explicit consideration in dispatch decision rules of the probability that an alarm is serious. Even if the immediate availability of surrounding units and related criteria can be ignored in the dispatch decision, it may be desirable to have two predetermined first responses for particular neighborhoods--one for alarms likely to be minor and a second for alarms likely to be more serious. Such a dispatch policy would employ the forecasting aspects of the Rand work, but not the decision rules.

In jurisdictions where such a scheme might be appropriate, however, one additional problem arises. Such a dispatch policy implies the willingness of fire protection officials to dispatch a potentially inadequate first response to an alarm from an alarm box with a history of false or inconsequential alarms. While the Professionals Panel indicated such policies are informally followed by some fire departments in their "problem neighborhoods," it would appear that formalization of such a dispatch plan could create many political and organizational conflicts.

#### 6.2.2 WHICH UNITS TO SEND?

In addition to describing how many fire suppression units to dispatch to a given alarm, a complete dispatching rule must answer the question, "Which units to dispatch?" At any given time, certain of the units in a region may be busy at fires. Thus, the "which" decision rule necessarily will be a dynamic one which depends on the current availability of companies.

In the overwhelming number of modern fire protection jurisdictions, this "which" decision is made on the basis of the "closest available units." If four engine companies are required, the four closest companies not occupied at other alarms are automatically chosen for dispatch.

As explained in Section 6.1.3, Carter, Chaiken, and Ignall [A-5] have studied the question of the best boundary between the response regions of two cooperating emergency units. Since the decision of which company to send becomes equivalent to the question of how to draw response district boundaries in the simple case of two units, their research also can be viewed as an analysis of dispatch policies. In this context, their principal results were that (under their severe assumptions) the best dispatch policy depended on the workload of the two units. When units are not very busy, the best policy is always to send the closer company. As one of the companies becomes much busier than the other, it may be desirable occasionally to dispatch the less busy unit -- even if it is not nearer to the alarm. This policy is optimal because it leaves the remaining, busier unit available to respond to additional alarms.



In [A-24] Ignall discussed the extension of this research to a complete rule for which units to dispatch. In particular, he considers the question, "Which  $N$  of the  $2N$  units in a given region should be dispatched to an alarm?" Like the earlier work in [A-5], Ignall makes the assumptions that alarms arise according to the Poisson probability distribution, with different alarm rates for different points in the region. More significantly, he continues to assume that the time a given company is in service on a particular alarm is independent of the locations of both the alarm and the fire house where the company is stationed. This assumption has the effect of ignoring the tendency of the response time part of in-service time to be longer when more distant units are dispatched.

Within these assumptions, Ignall investigates rules for the best units to dispatch under criteria varying from a simple average of the response times of all responding companies, to averages weighted more heavily on the response of the first units, and then to averages including weighting for the balance of workload between companies.<sup>1</sup> A statement of the problem of finding the units to dispatch under any of these weighted objective functions is shown to be a very large linear program.<sup>2</sup>

Ignall recognizes that this linear program is entirely too large to be solved each time units must be selected to respond to an alarm. However, the solution is greatly simplified if the overall average response time criterion is used to select optimal policies. In this special case (where workload balance and differences between first, second, and succeeding responses are ignored) the best policy is closely related to the Swersey criteria for how many to send discussed in Section 6.2.1.

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1. See Sections 5.3 and 5.4 for discussion of such criteria.
  2. A linear program is the type of problem in operations research which can be formulated as the minimization of a linear combination of the decision variables subject to inequality constraints which are themselves linear combinations of the decision variables.

Ignall's policy for which units to send is detailed in Table 6-7. It provides that an optimal decision is obtained by calculating a test criterion like the one presented in Table 6-6 for each available unit. Units with the lowest values of this criterion are the best ones to send to reduce overall average response time. As was the case in [A-5], this policy will not always result in sending the closest units.

In [A-25] Ignall reports limited testing of this criterion with Rand's computer simulation of the Bronx.<sup>1</sup> As anticipated, this testing produced an improvement in the workload balance between companies without significantly increasing average response time.

Like the Rand work on dispatching discussed in Section 6.2.2, Ignall's work appears to provide a methodologically sound answer to a range of problems in dispatch policy. However, the application of the work may be limited to very large and busy fire protection jurisdictions. Like the work in Section 6.2.1, the advantages of Ignall's policy over the simple "closest units" rule tends to be small unless it is typical that large numbers of companies are busy. In jurisdictions where the vast majority of companies are usually available, the "closest units" rule would appear to give very satisfactory results. Moreover, Ignall's scheme almost certainly would require some form of computerized information system to keep track of the best units to send at any given moment.

### 6.3 REPOSITIONING POLICIES

In Section 6.1, the problem of determining "home base" or "permanent" locations for fire companies was addressed. Though a fire jurisdiction may have several such positioning plans (e.g., one for each season of the year), a positioning plan is relatively permanent. It does not vary as particular emergencies develop.

The problem of developing a repositioning plan is the one of dealing with such emergency situations. When a substantial number of the fire suppression companies in a particular part of the jurisdiction are

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1. See Section 6.4 for discussion of this computer simulation.

TABLE 6-7. IGNALL'S POLICY FOR WHICH UNITS TO SEND

Criterion for company j on an Alarm of Type k at Point x:

$$t_j^* = t_j(x) + \theta_j(1 + (r - 1)) P_k$$

where  $t_j(x)$  = the time for unit j to respond to point x

$r$  = the ratio of the value of response time at serious fires to response time at other fires

$P_k$  = the probability an alarm of type k is serious

$\theta_j$  = a balancing factor increasing with the workload of company j.

Policy:

If n units are required, send the units j with the n smallest  $t_j^*$

unavailable because they are involved with serious fires, it may be necessary to reposition or "move-up" some available units to avoid leaving neighborhoods entirely unprotected.

Though repositioning or "move-up" is a very common practice in fire protection jurisdictions, only one set of research was identified for this study which dealt systematically with the repositioning problem. This research is the work of Swersey [A-54], Walker and Shinnar [A-61], Chaiken [6-10], and Kolesar and Walker [A-29] of the New York City Rand Institute.

The work began with an attempt to mathematically formulate the entire repositioning problem. In [A-54] Swersey presented the formulation shown in Table 6-8. Generally, this formulation selects the repositioning which minimizes a combination of city-wide average response time after the repositioning and the cost of company movements.

The formulation falls in the category of operations research problems called warehouse location problems. Warehouse location problems are generally quite difficult to solve. Some alternative solution schemes for Swersey's formulation were considered in Walker and Shinnar [A-61]. Both techniques for determining the exact optimal solution to the problem and schemes for obtaining approximate, heuristic solutions were investigated. Results indicate that the heuristic approach provides solutions which are nearly as good as the exact technique, and that the time required by the exact scheme is too large to be efficiently included in an operational system for repositioning.

In [6-10] Chaiken observed a deficiency in the Swersey formulation which would appear to make it unacceptable to fire service professionals. In particular, Chaiken noted that in practice the objective of a repositioning is usually to minimize the number of neighborhoods without some minimum "adequate" coverage, rather to minimize city-wide average response time.<sup>1</sup> Thus, Chaiken suggested

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1. See Section 5.4.4 for additional discussion of this "response balancing" question.

TABLE 6-8. SWERSEY'S FORMULATION OF THE REPOSITIONING PROBLEM

$$\text{Minimize: } \sum_j \sum_i \alpha_{ij} x_{ij} + \sum_j C y_j (1 - O_j)$$

$$\text{Subject to: } \sum_j x_{ij} = b \quad \text{for each } i$$

$$\sum_i x_{ij} \leq k y_j \quad \text{for each } j$$

$$\sum_j y_j = m$$

$$y_j = 0 \text{ or } 1 \quad \text{for all } j$$

$$0 \leq x_{ij} \leq 1 \quad \text{for all } i \text{ and } j$$

$$\text{where } y_j = \begin{cases} 1 & \text{if company location } j \text{ is to be occupied} \\ 0 & \text{otherwise} \end{cases}$$

$$x_{ij} = \begin{cases} 1 & \text{demand region } i \text{ is covered by a unit at company location } j \\ 0 & \text{otherwise} \end{cases}$$

$b$  = the number of surrounding companies which provide some measure of protection to any demand region

$k$  = the number of demand regions

$C$  = the fixed cost of any company movement

$\alpha_{ij}$  = a response time "cost" of having a unit at location  $j$  cover demand region  $i$

$$O_j = \begin{cases} 1 & \text{if company location } j \text{ is presently occupied} \\ 0 & \text{otherwise} \end{cases}$$

that a procedure for repositioning should include additional constraints requiring that each neighborhood have some minimum level of coverage after a repositioning.

The repositioning procedure which evolved in Kolesar and Walker's report [A-29] corrects this deficiency. Specifically, the repositioning problem is addressed in four steps. Step 1 identifies the need for relocation. A relocation is deemed required when none of the three closest companies to some neighborhood is free to respond to new alarms.

Step 2 selects the empty company locations which must be covered by a repositioning. The mathematical formulation of the problem addressed at this step is given in Table 6-9. The formulation requires that a minimal number of locations be selected for coverage by repositioned units in a way which will assure that each neighborhood has one of its closest three company locations occupied.

Step 3 determines companies which should be moved from their base positions to the empty positions being covered. A mathematical formulation of this step is given in Table 6-10. It requires that movements from occupied locations  $i$  to unoccupied locations  $j$  leave all neighborhoods covered by one of the three closest company positions. Within these constraints, the location is selected which minimizes the city-wide average response time which will result from the repositioning. An estimate of that response time is derived from the "square-root" schemes discussed in Section 6.1.1.

Implicit in the approach for Step 3 is a decision on where each unit selected for repositioning is to be placed. However, that selection is based on the average response time pattern which will result after the repositioning. In Step 4 of the Rand procedure, this repositioning plan is refined by considering the "cost" of relocating units. Given the empty company positions selected for coverage at Step 2, and the moving companies selected at Step 3, a final repositioning is derived which minimizes the cost (usually distance) required to relocate the selected units. The mathematical formulation of this step is given in Table 6-11.

TABLE 6-9. FORMULATION OF STEP TWO OF THE NYC-RAND  
RELOCATION PROCEDURE

$$\text{Minimize: } \sum_{j=1}^L x_j$$

$$\text{Subject to: } \sum_{j=1}^L a_{ij} x_j \geq 1 \quad i = 1, 2, \dots, K$$

$$x_j = 0 \text{ or } 1 \quad j = 1, 2, \dots, L$$

where  $K$  = the number of response neighborhoods

$L$  = the number of vacant firehouses

$$x_j = \begin{cases} 1 & \text{if firehouse } j \text{ is to be filled} \\ 0 & \text{otherwise} \end{cases}$$

$$a_{ij} = \begin{cases} 1 & \text{if firehouse } j \text{ can cover response neighborhood } i \\ 0 & \text{otherwise} \end{cases}$$

TABLE 6-10. FORMULATION OF STEP THREE OF THE NYC-RAND  
FELOCATION PROCEDURE

Response Cost Measure of Moving Unit  $i$  to Location  $j$ :

$$c_{ij} = (c_2 - c_1) \alpha_i (t + r_{ij}) + (c_2 - c_1) \alpha_j r_{ij}$$

where  $\alpha_\ell = \frac{\lambda_\ell \sqrt{A_\ell}}{v_\ell}$

$\lambda_\ell$  = the alarm rate in the primary response district around station  $\ell$

$A_\ell$  = the land area of the primary response district around station  $\ell$

$v_\ell$  = the average response velocity in the primary response district around station  $\ell$

$r_{ij}$  = the time required to travel from station  $i$  to station  $j$

$t$  = the time interval over which the relocation will be in effect

and  $c_1$  and  $c_2$  are constants of proportionality associated with the response of the nearest and second nearest unit in any area ( $c_1 \leq c_2$ ).

Formulation:

Minimize  $\sum_i \sum_j c_{ij} y_{ij}$

Subject to  $\sum_i y_{ij} = 1$  for all  $j \neq 0$

$\sum_j y_{ij} = 1$  for all  $i$

(continued)



TABLE 6-10. CONTINUED

$$\sum_i a_{ik} y_{io} + \sum_i \sum_{j \neq 0} a_{jk} y_{ij} \geq 1 \quad \text{for all } k$$

$$y_{ij} = 0 \text{ or } 1 \quad \text{for all } i \text{ and } j$$

where

$$y_{ij} = \begin{cases} 1 & \text{if the unit at } i \text{ is moved to station } j \text{ (} j = 0 \text{ implies} \\ & \text{a trivial move to station } i \text{)} \\ 0 & \text{otherwise} \end{cases}$$

$$a_{\ell k} = \begin{cases} 1 & \text{if a unit location } \ell \text{ can cover response neighborhood } k \\ 0 & \text{otherwise} \end{cases}$$

TABLE 6-11. FORMULATION OF STEP FOUR OF THE NYC-RAND  
RELOCATION PROCEDURE

$$\text{Minimize} \quad \sum_i \sum_j r_{ij} y_{ij}$$

$$\text{Subject to} \quad \sum_j y_{ij} = 1 \quad \text{for all } i$$

$$\sum_i y_{ij} = 1 \quad \text{for all } j$$

$$y_{ij} = 0 \text{ or } 1 \quad \text{for all } i \text{ and } j$$

where  $r_{ij}$  = the travel distance from station  $i$  to station  $j$

$$y_{ij} = \begin{cases} 1 & \text{if the unit at station } i \text{ is moved to station } j \\ 0 & \text{otherwise} \end{cases}$$

The optimization problems implicit in Step 2 and 3 are of the type called set covering problems in the literature of operations research. In general, such problems are very difficult to solve exactly, but many satisfactory approximate or heuristic schemes have been devised. Kolesar and Walker employ such heuristic procedures. Company positions are selected for coverage at Step 2 on the basis of covering first the location which will restore minimal service (at least one of the three closest companies available) to the largest number of uncovered neighborhoods. Positions are selected in this order until a minimal level of service has been provided to all neighborhoods in the jurisdiction.

The heuristic procedure used in Step 3 is similar. Companies are selected for relocation in the order which they will most improve the resulting city-wide response time coverage. Thus, the relocation which most improves the response situation is selected first, the one which most improves the remaining situation is selected second, and so on. The procedure continues until all empty positions to be covered have been filled.

Kolesar and Walker [A-29] report generally satisfactory testing of their procedure on a re-creation of the very busy night of July 4, 1969. Alarms actually received that night were processed through the proposed repositioning procedure. The recommended procedure performed at least as well as the manual dispatching which had actually been done on that night, and accomplished the necessary repositionings in a smoother, less erratic manner.

In spite of the apparent effectiveness of the Rand procedure in New York City, however, it appears that some caution is required in directly applying the techniques to other jurisdictions. Not only are the solution schemes at Steps 2 and 3 heuristic, and thus subject to error, but the division of the overall repositioning problem into four separate steps can add additional error. For example (as the authors point out), the selection of locations to cover at Step 2 should theoretically be combined with the selection of covering units at Step 3. Different positions might be selected for coverage if the difficulty of finding covering units were considered.

However, such a combining of Steps 2 and 3 would cause a considerable increase in the difficulty of solving the resulting set covering problems. This difficulty is the reason Rand elected not to pursue the combined approach. For New York City, their compromise between optimality and efficiency of solutions may be very appropriate. However, difficulties might arise in other cities.

A related problem with generalizing the Rand approach to other cities was raised by the Professionals Panel. An underlying assumption of all the Rand work is that relocations should be accomplished by the minimum number of company movements. This requirement has the effect of frequently moving relocating companies from their base positions, past occupied positions, to assigned vacant locations. When a city has a large number of fire companies located relatively close to one another, this approach would seem quite reasonable. However, the Professionals Panel indicated that a "sequential" repositioning--with more companies moving shorter distances--might be more appropriate in smaller, less dense jurisdictions. In such cities, the Rand formulation would need to be modified to allow repositioning to company locations made vacant by a previous repositioning.

Finally, it should be observed that even with the concessions made to computational simplicity in the Rand approach, a computerized dispatch facility probably would be required to operate the repositioning system. Thus, the technique automatically would be restricted to relatively large and sophisticated fire jurisdictions.

#### 6.4 COMPLETE POLICIES

In the three previous sections, the positioning, dispatching, and repositioning aspects of suppression company allocation policies were addressed separately. The research which was discussed often simplified the overall problem of developing a suppression resource allocation policy by ignoring interactions between positioning, dispatching, and repositioning rules.

Many of the researchers whose work was reviewed for this report have believed that such simplifications can provide only a first (but important) step in the development of a complete policy. A great deal

of insight may be gained from these more simplified analyses, and large numbers of excellent candidate policies may be developed. However, these researchers have concluded that a study of the way candidate policies fit together is appropriate before the potentially costly implementation of a policy is attempted.

In this section, this second, complete policy step of resource allocation is addressed. All research identified for this report which involves the capability to evaluate complete policies employs computer simulations. Specifically, computer programs are developed which:

- Reproduce a typical sequence of alarms
- Execute the proposed allocation policies by actually selecting responding units and generating typical times for the units to go to the scene, deal with the alarm, and return to their stations
- Tabulate various measures of the performance of the allocation policies

Thus, instead of experimenting in the actual fire service environment, the essential events in the operation of a fire suppression program are reproduced in a computer, and experiments are performed with this computer simulation of the environment.

Three major computer simulation studies were reported in the research reviewed for this report. A first was developed as part of the New York City Rand Institute's work in New York City [A-6, A-7]; another is an element of the Pinnell-Anderson-Wilshire Associates study of Wichita Falls, Texas [A-2, A-64]; and a third is part of the Nilsson and Swartz study of Alexandria, Virginia [A-41]. Another simulation design is proposed in Weitz [6-39], but the proposal apparently was never implemented. Other simulations were mentioned in Mitchell [A-40] and Gordon, Drozda, and Stacey [A-15] but were insufficiently documented for analysis.

The scope and objectives of the three principal computer simulations and one proposed by Weitz were quite varied. The Weitz concept would have simulated the entire fire service environment—going far beyond company resource allocation policies. For example, the proposal includes the simulation of fire insurance and fire prevention

effects on fire losses. It is conceivable that the difficulty of developing such a comprehensive model is the reason no literature was found showing implementation of Weitz's design.

The Rand simulation is limited to suppression company allocations, but is designed to deal comprehensively with positioning, dispatching, and repositioning aspects of such policies. Thus, the simulation has the capability to execute repositioning and rather complex dispatching policies, as well as the more routine movements of suppression forces.

The problem addressed in the Pinnell-Anderson-Wilshire and Associates study is to construct a model of fire department operations that can quantitatively evaluate positioning and dispatch strategies. The model does not consider the problem of relocation. Thus, its applicability would seem to be limited to smaller cities.

The objective of the Nilsson and Swartz simulation is even more limited--to evaluate the response time effect of changes in fire station location patterns in the city of Alexandria, Virginia. Dispatch activities are included, but not varied.

All of the simulation models are constructed in terms of events or major changes in the suppression environment. In Rand's simulation, incidents begin with the outbreak of a fire. After a predetermined time, the alarm is turned in. The allocation policy then is used to decide which companies to send to the alarm, and after a delay (which varies with the number of alarms currently being processed), the companies are dispatched. As they are dispatched, the arrival of units on the fire scene is estimated on the basis of the locations of the alarm and responding companies. The first unit to arrive reports to the dispatching office on the conditions encountered. If too many units have been dispatched, some are sent back to their houses; if the fire is serious, more units are dispatched. Companies are released from the scene according to their arrival time and the predetermined requirements of the fire incident. After release, the companies proceed back to their stations. Depending on the severity of the fire, they then will be ready for a new incident or will be given a recovery period.

The model uses an input program which generates the set of fire incidents. The incidents are described according to alarm box location, the arrival rate of incidents at the box, and the type of incident, including the number and type of companies required to extinguish it. An analysis program is run after the simulation is complete, to determine the performance of the tested policy. Performance is measured in terms of the response times of the first, second, third, and each succeeding company on the scene of fire alarms.

The Pinnell-Anderson-Wilshire and Associates model is similar but less detailed. A Monitor section initiates alarms and maintains historical records. The Response Strategy section determines the particular strategy being used, selects and dispatches the proper vehicles, and calculates their arrival time. The Alarm Activity section receives control when the first unit arrives on the fire scene. It calculates the time under control and time out of the fire, as well as the time each unit arrives back at the station. When a unit returns to the station, the Back in Service section completes each unit's history record. A Wrap Up section completes any remaining calculations.

The model is accompanied by an initialization program and an analysis program. The initialization program sets the pattern of alarm occurrence through time, the alarm locations, the travel speeds, and on-site times. The analysis program reviews the performance of the tested policy in terms of both response times and estimated fire losses.

The Nilsson and Swartz simulation model was used exclusively to compare location patterns suggested by the two positioning models discussed in Section 6.1.2. Thus, it is even less detailed. The model begins when a fire breaks out. An assignment routine acts as the dispatcher by determining which resources will serve the alarm. These resources then travel to the fire scene and remain there for a specified length of time. At the end of this time, the units return to their stations. When the last resource has returned, the case is terminated.

The model does not provide for delayed response time when resources are occupied, for interruption of low priority service, or for the relocation of idle units. Thus, it probably is adequate for the

purpose of comparing alternative location patterns, but if it were to be used, for example, to predict response times, its lack of realistic detail would cause inaccuracies.

In order for a simulation model to be useful for experimenting with proposed policies, it should be validated to assure that the model conforms reasonably well to the true model environment. All three of the simulations appear not to have been satisfactorily checked in this way.

The Rand work discusses the possibility of using simple mathematical approximations to test parts of the simulation model, but no details are provided. The current operating policy of the New York Fire Department was run in the simulation, and the results used as a benchmark for comparing other policies. However, there is no discussion of how well the output from the simulation run of the current policy compared with actual experience.

In the Pinnell-Anderson-Wilshire and Associates study, output from the alarm generation routine was compared with actual alarm data by appropriate statistical tests. However, no other discussion of validation was included in the report.

The Nilsson and Swartz report provide very little information on validation. Data derived in earlier Alexandria work apparently were used to develop input for the simulation, but no details are provided.

One example of an element of the simulations which would appear to require additional validation is the estimation of response times. All three models apparently used simple time-to-distance relationships like those discussed in Section 5.1.3 to calculate times from the map locations of alarms and the houses of responding companies. While the evidence of Section 5.1.3 indicates that such estimation schemes may give fairly adequate approximations of travel time, additional validation would be required before a simulation involving such estimates could be used to study other response time formulas. Some of the work discussed in Section 6.1.1 attempted, in effect, to study the value of one set of response time estimators by using a simulation which employed quite similar estimators.



A satisfactory simulation study should also provide some adjustments for misleading results which may arise in simulation outputs. Since the situations simulated in a computer are randomly generated from probability distributions of typical values, it is possible that a particular computer run could contain a very unusual sequence of events. For example, an unusually high rate of alarms might be experienced over a short simulated period even though the average through a longer period would conform to the typical values. This difficulty with output of simulations was handled very adequately in the Rand work, but no information is provided on any corresponding caution in the other simulation studies.

In addition to these methodological reservations, it appears an open question whether results obtained from such complex computer simulations justify the considerable analytic resources required to develop them. Certainly in New York, and to a lesser extent in Wichita Falls and Alexandria, the authors report that considerable insight was gained from simulation experiments. Allocation policies which appeared beforehand to be helpful sometimes proved surprisingly ineffective when subjected to simulation analysis.

However, the design, programming, data collection, and validation efforts required to develop a complex computer simulation are considerable. It is not clear from the results obtained that this investment can be justified except in very large fire jurisdictions where a great deal of resource allocation research is anticipated.

## 6.5 SUMMARY

Fire suppression resource allocation questions at the company level include: "Where should suppression companies be positioned?", "What companies should be dispatched to particular alarms?", and "How should companies be repositioned during serious fires and emergencies?" Numerous researchers have proposed or tested procedures for investigating these questions under various assumptions about the fire suppression environment.

By far the largest part of this research has been concerned with positioning, i.e., selection of relatively permanent, "home base"

locations for suppression companies. This research has produced:

- A relatively well-validated set of simple mathematical formulas for rough or preliminary positioning, which are derived from the homogeneous demand case where the alarm rate is assumed constant over the entire region being studied, but can be more widely applied
- A collection of more detailed and complex formulations which position companies at sets of fixed positions
- A limited number of probabilistic results which have implications for the performance of positioning plans in environments where the nearest company to an alarm is not always available

Taken together, these results appear to largely exhaust the possible approaches to the positioning problem, but much more experience with the techniques is required to more thoroughly identify their strengths and weaknesses. It would be particularly useful to have further evidence on the degree to which the quality of the resulting positioning plan is improved when the simple formulas available from the homogeneous case are replaced by the more complex covering, or fixed location schemes.

A considerable amount of research also has been performed (largely by the New York City-Rand Institute) on rules for assigning companies to alarms. This research has demonstrated the value of explicit consideration of the probability that a given alarm signals a serious fire, and produced a set of optimal (under appropriate assumptions) decision rules for both the question, "How many of each type of company to dispatch?" and the question, "Which particular units should be assigned to form the desired number of dispatched units?" These decision rules do not always assign the closest available units.

Pending more widespread implementation, it appears that this research on dispatch rules provides fairly satisfactory answers to the above questions. However, it is not clear whether rules other than the commonly used "assign a predetermined number of the nearest units" rule are necessary except in very large cities. When company workloads are low, the more complex decision rules collapse into this

simple and widely used policy.

The New York City-Rand Institute also has performed the only research located for this report on the problem of repositioning, i.e., temporarily moving free companies into areas left unprotected when a large number of companies are occupied at serious fires. This research has produced a simple and intuitive scheme for computerized repositioning which appears to meet the needs of New York City. However, some modification of the approach probably would be required to fit the environment in other jurisdictions. Moreover, the repositioning problem is probably only complex enough to require more than dispatcher's judgment in large fire jurisdictions.

Finally, a number of computer simulation routines have been developed which permit more "realistic" testing of complete suppression allocation policy alternatives. Where these routines have been employed, they appear to have yielded worthwhile insight. However, many of the details of the simulations have not been thoroughly validated, and it is not clear that a relatively complex and expensive effort to develop a simulation can be justified in other than the very largest fire jurisdictions.

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## CHAPTER 7

### FIRE PREVENTION

Most fires are started by people. Some of the frequent causes are careless smoking, children playing with matches, careless use of flammable liquids, and combustibles near heaters. The fire chiefs on the Professionals Panel had no illusions concerning the difficulty of making people more fire safety conscious. "We can't control people," they said. The Panel unanimously agreed, however, that both fire incidence and fire damage could be reduced through prevention efforts and that prevention deserved added emphasis in the fire protection service.

The Report of the National Commission on Fire Prevention and Control [7-30] states that, "In the Commission's estimate, about 70 percent of the fires that occur in buildings can be attributed to the careless acts of people, and together these fires caused by human action account for more than \$800 million in property losses." The report further points out that this is only part of the story. Much loss could be avoided and many injuries and deaths prevented if people knew how to react to a fire -- whatever its cause. The report goes on to recommend a national program in fire safety education.

Much more has been written concerning the importance of fire prevention. Howard Boyd [7-1], Nashville Fire Marshall, stated in 1973:

We can no longer pay the price of maintaining enough manpower and equipment to control the worst possible fire that could befall a community. We must alter our viewpoint from one of suppression and control to emphasis on fire prevention and inspection, by building in every office, factory, and home as much fire protection as we can. At present the emphasis is being placed at the wrong end of the spectrum.

Laiming [7-19] also stressed the need for fire prevention effort and suggested the following:

- A national coordinating body for exchange of statistical data (on fire loss and causes) in agreed-upon form to facilitate research

- Participation of fire inspectors in the activities of the building department (e.g., approval or rejection of building plans)
- Better enforcement of standards
- Increased penalties for negligence leading to fire

It is interesting to note that progress has been made on at least some of Laiming's suggestions. The NFPA has established a uniform incident reporting system, UFIRS<sup>1</sup>, and in November 1973 this system was operating in seven California cities [7-12, 7-13].

Virtually all fire departments recognize fire prevention as an important part of their duties and maintain a special officer or bureau charged with this function. However, there seems to be considerable feeling among fire service professionals that prevention effort is not given the resources and emphasis which it deserves and must have if fire losses are to be reduced.<sup>2</sup> Several writers place at least a part of the blame on the ISO Grading Schedule, which allocates only a small proportion of the total possible points to fire prevention.<sup>3</sup> Boyd [7-1] claimed that the low priority given to fire prevention by the Grading Schedule is a deterrent to improved fire prevention. Homer [7-34], in a statement before the Subcommittee on Rates and Rating Organizations of the National Association of Insurance Commissioners, criticized the Grading Schedule for its traditional emphasis on suppression and pointed out that the 1973 changes actually increased this emphasis. He stated that, "It is generally agreed and supported by the Commission's findings that additional investments in fire prevention are likely to yield far greater returns in reducing fire deaths and property losses than additional investments in traditional suppression approaches."

For whatever reason, it appears that fire prevention activities receive only a small portion of the resources and manpower of most fire departments. Accurate data on allocation of resources is difficult, if not impossible, to obtain because suppression and prevention activities often are, and should be, carried out by the same personnel. The search

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1. UFIRS is discussed further in Section 4.1.

2. See Section 2.3.4.

3. The ISO Grading Schedule is discussed in Section 2.5.

of fire-related literature failed to turn up a single report showing a cost breakdown between prevention effort and extinguishment effort.

## 7.1 PREVENTION ACTIVITIES

Fire prevention activities in most urban fire departments include some or all of the following:

- Inspection of structures and premises
- Public education
- Assistance in training industry in self-protection
- Supervision of safety of public assembly
- Participation in preparation and revision of laws and fire regulations
- Licensing of hazardous processes and storage
- Enforcement of regulations
- Investigation of fires
- Disposition of arson cases

The main focus of fire department prevention activity is in the area of building inspections. The purposes of inspections are: (1) to detect violations of fire ordinances and codes and obtain corrections, (2) to detect and secure correction of fire hazards, such as rubbish, unsafe appliances, and unsafe handling of combustibles, and (3) to increase fire safety consciousness of managers and occupants of the buildings. In departments where inspections are carried out by fire fighters, there is the added benefit of familiarization with the buildings.

According to the report "Design for the Future" [7-31], the Burbank Fire Department has the following inspection programs:

- Target hazard inspection (four times per year)  
All large or complex concentrations of burnable value or life hazard.
- Company fire prevention inspection (two times per year)  
Normal business and industrial occupancies. Inspection by fire suppression personnel under direction of Fire Prevention Bureau.
- Church/school inspection (four times per year)  
Inspection and familiarization program.

- Multiple residence inspection (annually)  
Inspection of apartment units.
- Special occupancy and hazard inspection program  
Inspection by fire prevention personnel of special occupancy groups, such as motels, hotels, mobile homes, restaurants, nursery schools, theatres, and automatic sprinkler installations.
- Home inspection program  
Inspection of private residences.

The report recommends a program of hazard and loss analysis to better determine the nature of fire problems and detect trends. The types of analysis recommended to assist the fire prevention effort are:

- Location of fire within a tract versus trends in fire activity
- Type of occupancy versus fire prevention inspection
- Industrial processes involved in fire versus fire prevention inspection
- Location of fire versus changes in zoning and population densities
- Fire trends by hour, day, or week versus requirements for inspection

The Pinnell-Anderson-Wilshire report for the City of Wichita Falls [A-64] presents a fire hazard survey form for use in checking for potential fire hazards. (See Figure 7-1.) The frequency of inspection of buildings of various occupancy types is not listed in the report; however, a computer-aided inspection scheduling and reporting system is developed.<sup>1</sup>

The Charlotte Fire department also uses a computer-assisted fire prevention reporting system. Their description of the reports provided by the system is shown in Figure 7-2.<sup>2</sup> The data in these reports have obvious

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1. See Subsection 7.2 for further discussion of computer-based inspection scheduling. Chapter 4 also discusses the role of fire information and communications systems in fire prevention.

2. The Burbank and Charlotte fire prevention and reporting systems are cited as examples of such computer-based systems. They are not the only such systems in existence. Section 4.1 is devoted to broad management information systems for fire service and discusses the Burbank and Charlotte systems as well as others which have been described in the open literature.

ACTIVITY NAME _____		ACTIVITY ADDRESS _____		TRAFFIC ZONE _____	
HAZARDOUS CONDITION	YES NO	SURVEY ITEMS	SURVEY SUMMARY		
<div style="display: flex; flex-direction: column; align-items: center;"> <div style="width: 10px; height: 10px; border: 1px solid black; margin-bottom: 2px;"></div> <div style="width: 10px; height: 10px; border: 1px solid black; margin-bottom: 2px;"></div> <div style="width: 10px; height: 10px; border: 1px solid black; margin-bottom: 2px;"></div> <div style="width: 10px; height: 10px; border: 1px solid black; margin-bottom: 2px;"></div> <div style="width: 10px; height: 10px; border: 1px solid black; margin-bottom: 2px;"></div> <div style="width: 10px; height: 10px; border: 1px solid black; margin-bottom: 2px;"></div> <div style="width: 10px; height: 10px; border: 1px solid black; margin-bottom: 2px;"></div> <div style="width: 10px; height: 10px; border: 1px solid black; margin-bottom: 2px;"></div> <div style="width: 10px; height: 10px; border: 1px solid black; margin-bottom: 2px;"></div> <div style="width: 10px; height: 10px; border: 1px solid black; margin-bottom: 2px;"></div> <div style="width: 10px; height: 10px; border: 1px solid black; margin-bottom: 2px;"></div> <div style="width: 10px; height: 10px; border: 1px solid black; margin-bottom: 2px;"></div> <div style="width: 10px; height: 10px; border: 1px solid black; margin-bottom: 2px;"></div> <div style="width: 10px; height: 10px; border: 1px solid black; margin-bottom: 2px;"></div> <div style="width: 10px; height: 10px; border: 1px solid black;"></div> </div>	EXIT FACILITIES	DATE OF SURVEY <div style="display: flex; gap: 5px;"> <div style="width: 20px; height: 20px; border: 1px solid black;"></div> <div style="width: 20px; height: 20px; border: 1px solid black;"></div> <div style="width: 20px; height: 20px; border: 1px solid black;"></div> </div>			
	ON-SITE PROTECTION	HAZARDOUS CONDITION FOUND <div style="display: flex; align-items: center;"> <div style="width: 20px; height: 20px; border: 1px solid black; margin-right: 5px;"></div> </div>			
	GENERAL HOUSEKEEPING	1-Yes			
	COMBUSTIBLE MATERIAL IN OR OUTSIDE BUILDING	2-No			
	TRASH RECEPTACLES	DATE OF LAST SURVEY <div style="display: flex; gap: 5px;"> <div style="width: 20px; height: 20px; border: 1px solid black;"></div> <div style="width: 20px; height: 20px; border: 1px solid black;"></div> <div style="width: 20px; height: 20px; border: 1px solid black;"></div> </div>			
	INCINERATORS	SURVEY FREQUENCY <div style="display: flex; align-items: center;"> <div style="width: 20px; height: 20px; border: 1px solid black; margin-right: 5px;"></div> </div>			
	OPERATIONS USING FLAMMABLE SUBSTANCE	1-Monthly			
	HEAT PRODUCING DEVICES	2-Quarterly			
	PERMANENT WIRING	3-Semi-Annually			
	NATURAL GAS CONNECTIONS	4-Annually			
	FUSES	NUMBER OF FOLLOW-UP INSPECTIONS <div style="display: flex; align-items: center;"> <div style="width: 20px; height: 20px; border: 1px solid black; margin-right: 5px;"></div> </div>			
	STORAGE OF FLAMMABLES	FIRE STATION ASSIGNMENT <div style="display: flex; align-items: center;"> <div style="width: 20px; height: 20px; border: 1px solid black; margin-right: 5px;"></div> </div>			
	SMOKING PRACTICES	COMMENTS: _____			
	STORAGE OF MATERIAL SUBJECT TO SPONTANEOUS HEATING	_____			
	COMPRESSED GAS	_____			
VENTILATION	_____				
TEMPORARY ELECTRICAL DEVICES	_____				
EXPLOSIVE MATERIAL	_____				
RADIOACTIVE MATERIAL	_____				
HAZARDOUS CHEMICAL STORAGE	_____				
OTHER, SPECIFY _____	SURVEYOR: _____				

<p>(1) EXIT FACILITIES - Are exits blocked or locked, is panic hardware locked?</p> <p>(2) ON-SITE PROTECTION - Are extinguishers full and operable, date of last inspection (should be inspected yearly), are sprinkler system valves off or on, are any caps or valves missing from standpipe system, is hose on standpipe system in good condition?</p> <p>(3) GENERAL HOUSEKEEPING - Is lint and dust present in vents, are the premises generally neat and orderly?</p> <p>(4) COMBUSTIBLE MATERIAL STORAGE - Are there any large or hazardous concentrations of combustibles (wood, paper, baled goods, trash, etc.), are combustibles in hazardous locations (under stairways, too close to sprinkler heads - 12" minimum clearance)?</p> <p>(5) TRASH RECEPTACLES - Are they of the proper type (metal, not paper or wood), are trash receptacles in hazardous locations?</p> <p>(6) INCINERATORS - Are they in good general condition (include cleaning)?</p> <p>(7) OPERATIONS USING FLAMMABLE SUBSTANCES - Are large volumes of flammable substances used (spraying or dipping operations, sealers, fumigants, etc.), are separate facilities used for large volume operations, is there a heavy concentration of fumes?</p> <p>(8) HEAT PRODUCING DEVICES - Is the location hazardous with respect to combustible materials (heaters, pilot lights, light bulbs, etc.)?</p> <p>(9) PERMANENT WIRING - Do any noticeable hazards exist, are there any heavy load wires running unprotected through walls?</p> <p>(10) NATURAL GAS CONNECTIONS - Are there any unusually long gas lines, are they of the proper type (copper)?</p> <p>(11) FUSES - Is the fuse box in good general condition, are there any 'jumped' or short-circuited fuses, are breaker switches free and not taped or wired?</p>	<p>(12) STORAGE OF FLAMMABLE MATERIALS - Are flammables stored in metal containers (NOT plastic, glass, cardboard), are flammables stored in hazardous location?</p> <p>(13) SMOKING PRACTICES - Is smoking regulated, should smoking be regulated?</p> <p>(14) STORAGE OF MATERIAL SUBJECT TO SPONTANEOUS HEATING - Are there large accumulations of oily rags, mineral oils, charcoal, etc., are such items stored in proper containers, is location hazardous to other facilities?</p> <p>(15) COMPRESSED GAS - Are compressed gas cylinders stored separately and well anchored?</p> <p>(16) VENTILATION - Is ventilation effective, are there large concentrations of fumes?</p> <p>(17) TEMPORARY ELECTRICAL DEVICES (Extension Cords) - Are extension cords in good condition, has temporary wiring (ext. cords) been converted to permanent wiring?</p> <p>(18) EXPLOSIVE MATERIALS (Dynamite, Blasting Caps, Plastic Explosives) - Are explosives stored safely, are they well marked?</p> <p>(19) RADIOACTIVE MATERIAL - Are they well marked, are they stored safely?</p> <p>(20) HAZARDOUS CHEMICAL STORAGE - Are hazardous chemicals stored in safe containers, are they well marked, is location hazardous?</p> <p>(21) OTHER - Include any remarks pertaining to specific hazards as indicated above, or any other situation which is believed to be unsafe or hazardous either to life or property.</p>
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**FIGURE 7-1. FIRE HAZARD SURVEY, CITY OF  
WICHITA FALLS**

(Source: Pinnell-Anderson-Wilshire [A-64])

**CHARLOTTE FIRE DEPARTMENT**  
**FIRE PREVENTION REPORTING SYSTEM**

It became evident some two and one-half years ago, that the ever increasing records work load of the Fire Prevention Bureau could no longer be handled by our existing staff. We either had to employ additional secretarial personnel or provide some means of speeding up work processing. We explored the possibilities of using electronic data processing and determined that the use of this media would both be practical and economical. As of this writing, we have been using E. D. P. for two years for all of our Fire Prevention records. The benefits of this system surpassed our original expectations.

Only two recording documents are required for the system which has greatly simplified our data gathering process. Reports generated from the information gathered by these documents are provided on a monthly basis and are bound in a single book, which is kept at a work desk. All information is given on a current monthly and year-to-date basis.

Six programs are utilized to produce our reports. The first program provides the following information: the number and type of inspections made where the inspections were made (the fire district, outlying areas); inspections by land use (hospitals, schools, nursing homes, etc.); who made the inspection; and whether the inspection was an initial inspection or a re-inspection. Summary totals for each of the categories are provided.

The second program provides the number of fire drills conducted, programs presented, and people in attendance by type of occupancy (using property classification codes from the NFPA 901 standard code book). This information is provided for the work performed by each inspector and for the total work performed by the Fire Prevention Bureau. This program provides supervisors with management information. It answers the who, what, when, and where questions that pertain to work performed.

The third program provides the number of permits that were issued; who issued them and what kind they were. Total permits issued and totals in each category are provided.

The fourth program provides the number of inspections performed in each of the land use categories by each inspector and total for Bureau. When inspections by land use are compared with fires by land use our effectiveness can be evaluated to some extent and occupancy with high incidents of fire can be concentrated upon.

The fifth program provides the number of violations found in each category. By comparing violations found with fire causes, we are able to determine in which areas we have been least effective and can tailor our inspections to meet the needs of our city.

The sixth program provides the number of inspections performed by each inspector and the status of the inspection. Satisfactory inspections, unsatisfactory inspections, inspections remedied, and inspections still pending).

We have designed our data base with an eye toward future information needs and have attempted to make it broad enough to meet these needs.

More information about these programs is available at the Charlotte Fire Department, 125 South Davidson Street, Charlotte, North Carolina, 28202.

**FIGURE 7-2. CHARLOTTE FIRE PREVENTION REPORTING SYSTEM**  
**(Source: Charlotte Fire Department [7-5])**



implication for fire prevention. The Uniform Fire Incident Reporting System developed by the NFPA [7-12, 7-13] also provides fire data which could be useful in fire inspection and other prevention activities. However, the only published research concerning inspection frequencies related to fire hazard is Miller's work, which is discussed in Subsection 7.2.

Education of the public concerning fire safety is a never-ending task of the fire service. Reports of public fire safety education campaigns are contained in [7-35], [7-11], [7-21] and [7-3]. All of these are testimonials to success. However, fire safety education is a difficult task and, according to the Report of the National Commission on Fire Prevention and Control, not very well done. The estimated percentage of building fires and losses attributable to human action is shown in Table 7-1. The losses paint a dark picture.

The report cites two studies which provide evidence that public education programs reduce fire loss. The first involved an area in southeast Missouri [7-14] where an intensive public fire safety education program reduced the fire death rate from 12.9 to 7.4 per 100,000 population in three years (1966-1969). A similar study carried out eight years earlier in Arkansas [7-18] focused on the misuse of electrical wiring systems and petroleum products, plus use and storage of flammable products near heating units. The first year of a public education program cut burn injuries by half.

In any discussion of effectiveness of public fire safety education, the "Smokey Bear" campaign for forest fire reduction is certain to be cited as an example of effectiveness. Public service advertising has carried "Smokey Bear" fire safety messages. During these years, the forested land area for which statistics are kept has doubled and the public use has probably increased about tenfold. Yet, forest fires have been reduced from about 200,000 annually to 105,000 in 1971. The report points out that the estimated savings in natural resources are in the neighborhood of \$17 billion.

The report discusses a number of private organizations and municipalities which have innovative programs of fire safety education. However, these serve as isolated examples of what can be done. The Commission outlines and recommends a national program for fire safety education as

TABLE 7-1. ESTIMATED PERCENTAGE OF BUILDING FIRES AND  
LOSSES ATTRIBUTABLE TO HUMAN ACTION

Cause	(1) Percent attributed to human action	(2) Number of fires <sup>1</sup>	(3) Number of fires attributed to human action (Col. 1X2)	(4) Property loss <sup>1</sup>	(5) Property loss attributed to human action (Col. 1X4)
Heating and cooking equipment.....	75	157,700	118,275	\$ 172,895,000	\$129,671,250
Smoking and Matches.....	100	118,400	118,400	98,344,000	98,344,000
Electrical.....	50	160,900	80,450	271,269,000	135,634,500
Rubbish, ignition source unknown....	75	34,400	25,800	21,754,000	16,315,500
Flammable liquid fires.....	75	64,900	48,675	53,931,000	40,448,250
Open flames and sparks.....	75	74,100	55,575	100,156,000	75,117,000
Lightning.....	0	22,200	-	40,335,000	-
Children and matches.....	100	70,400	70,400	72,285,000	72,285,000
Exposure (to another fire).....	0	23,200	-	42,148,000	-
Incendiary (suspicious).....	100	72,100	72,100	232,947,000	232,947,000
Spontaneous ignition.....	33	15,700	5,233	25,606,000	8,535,000
Gas fires and explosions (not re- ported elsewhere).....	50	8,200	4,100	21,074,000	10,537,000
Explosions (miscellaneous and un- classified).....	50	4,400	2,200	5,212,000	2,606,000
Totals.....		826,600	601,208 <sup>2</sup>	\$1,158,046,000	\$822,440,500 <sup>3</sup>

<sup>1</sup>Loss data from "Fires and Fire Losses Classified," Fire Journal, September, 1972 (pp.65-69). Data in this table exclude two categories where human action cannot be estimated (i.e.: "Unknown or Unidentified" and "Miscellaneous Known").

<sup>2</sup>72.8 percent.

<sup>3</sup>71.2 percent.

(Source: "America Burning" [7-30])

follows:

- Multimedia public service education
- Intensive local education
- Education of children in schools

The estimated costs and potential savings of such a program are shown in Table 7-2.

Apparently there has been no research on any aspect of public fire safety education. Questions concerning media effectiveness, population strata to which education should be directed, cost-effectiveness measures, and educational needs have not been carefully examined.

Fire investigations, including the matter of arson, provide data inputs to fire prevention management. The Burbank report [7-31] mentions fire investigations and points out that in the U.S. fires are traditionally treated as "accidents" for which no blame can be laid. European countries tend to fix blame and impose penalties. The report recommends that, "Our investigations should be conducted with the ultimate objective in mind of placing the responsibility and prosecuting under the law for all unlawful acts."

The literature search for this study disclosed only one research effort related to arson. Vernon and Bigger [A-60] studied the dimensions of juvenile arson and false alarms for the urban areas of San Diego. Two hundred cases from a file of 713 cases of juvenile arson and false alarms were analyzed by frequency tabulations. Both false alarms and arson were found to be "little boy" problems not limited to any socioeconomic group or ethnic category. Most of the offenses were committed by young children who were playing or experimenting with fire or by older youths, usually in their early teens, who became involved for more complex reasons -- typically of a family or personal crisis nature. The report recommends increased attention to fire safety education in schools and counseling to alleviate the juvenile arson problem in San Diego.

The study was in response to an increasing juvenile arson problem in San Diego, and there are no other such studies to provide a basis for comparison with other cities. Our Professionals Panel, however, stated that the findings were consistent with their own experiences. In short, the report confirms what most fire service professionals already know.

TABLE 7-2. ESTIMATED ANNUAL SAVINGS AND COSTS OF A  
FIRE SAFETY EDUCATION PROGRAM

Program	Estimated savings			Estimated Federal cost
	Lives	Injuries	Property	
Nationwide multimedia public service education program.....	120	3,000	\$27,000,000	\$1,500,000
Intensive local education programs (directed to 5 percent of Nation's population with highest life loss risks).....	76	1,900	4,300,000	2,100,000
Nationwide elementary schoolchild education.....	66	1,600	8,700,000	6,000,000
Total.....	262	6,500	\$40,000,000	\$9,600,000

(Source: "America Burning" [7-30])

The subject of fire regulations and codes, although vital to fire prevention, was not specifically included in the literature search for this evaluation. For the most part, these are legal matters to which the fire service administrator may and should contribute, but they are not wholly within his authority or responsibility. No research dealing with the effectiveness of codes or regulations was found. Furthermore, no reference to any such research can be found in any of the research reports and related publications which were located and obtained for this project. It seems possible that none exists.

## 7.2 PREVENTION RESOURCE ALLOCATION

Schaenman and Swartz [7-24] state that, to their knowledge, there have been no studies that definitely prove the effectiveness of fire prevention efforts, and they suggest that it would be extremely valuable if someone were to devise a controlled experiment to evaluate the effectiveness of various types of fire prevention efforts. The literature search conducted for this evaluation project confirms that there are no studies which definitely prove the effectiveness of fire prevention effort.

Miller [A-38], in a study conducted in conjunction with the Atlanta Fire Department in 1973, considered the following three problems related to fire prevention management:

- What should be the frequency of scheduled routine inspections in each type of building occupancy in each area of the city?
- How should inspection districts be formed for a prescribed number of inspectors?
- How should routine building inspections be scheduled?

Miller stated that the problems are interrelated but, because of the large size of the overall problem and complex interrelationships involved, he chose to consider the first two problems, i.e., frequency (rate) of inspections and districting, simultaneously and treat the scheduling problem separately.

Miller assumed that inspection frequencies apply to occupancy type rather than individual structures, but provisions are made for treating buildings that have unusual hazards separately. The criterion used by

Miller in his model is the "total expected seriousness" (i.e., the potential seriousness multiplied by the expected number of fires and summed over all occupancy types.) Thus, the idea is to choose those inspection frequencies and district boundaries which result in minimum total expected seriousness of fires in the city. This criterion places emphasis on occupancy types where potential loss of life or property value is very high, although the average actually experienced may be quite low (e.g., hospitals and nursing homes).

The parameters of Miller's model require estimates of the potential seriousness of structure fires in each occupancy type and the probability of "ℓ" fires (in a year) in structures of each occupancy type for various values of "ℓ." The probabilities must be expressed as a function of inspection frequency. In order to determine the nature of this functional relationship, Miller conducted a controlled experiment with the Atlanta Fire Prevention Bureau. The experiment consisted of conducting routine inspections in predetermined buildings. Some buildings in each occupancy type were inspected once per six months, others once a month. Results of the first six months were used to establish estimates of fire probabilities as a function of inspection frequency. Unfortunately, the time period over which the study was conducted was too short, and data were insufficient to obtain statistically significant relationships in most cases. However, by combining objective estimates with subjective probabilities obtained from Atlanta fire service personnel, Miller was able to arrive at estimated values for the probabilities.

The Professionals Panel felt that the solutions to the research problems in Miller's study would be "valuable" to "very useful." They agreed that "potential seriousness," even subjectively obtained, is a satisfactory criterion. However, they indicated that the assumptions of independence between "time required to perform an inspection" and "inspection rate" was debatable. They also felt that the model would not be applicable to most cities.

With regard to the inspection scheduling problem, Miller developed a model formulation which utilized work-load balance as the criterion. He discussed solution procedures, but did not develop a specific solution procedure.

Pinnell-Anderson-Wilshire [A-64, 7-29] developed a computer-based inspection and scheduling system for the City of Wichita Falls. Their computer programs generate, at the beginning of each month, a list of inspection activities to be performed during that month. Information concerning completed inspections is fed back into the system and work not performed one month is rescheduled to the next.

### 7.3 SUMMARY

In spite of the fact that many speakers and writers attest to the importance of fire prevention, there has been very little emphasis on improvement of prevention effort. Typically, the lion's share of a fire department's operating budget goes for suppression -- probably because that is where it will do most to increase or maintain the ISO Grading. At the same time, however, fire protection service managers decry the erosion of admiration and esteem which the public holds for the fire service.<sup>1</sup>

It is possible that increased attention to fire prevention could help to restore public esteem. Fire protection service managers fail to appreciate that excessive emphasis on suppression capability has low visibility and may create a negative reaction on the part of the public. For the average John Q. Public, the sight of big, shiny fire engines sitting in the fire house with lots of firemen waiting for the next alarm is a thing which he may find irritating. For him a fire is a rare event. Odds are that he has never been personally involved in a fire and he may not even be acquainted with anyone who has suffered that catastrophe. On the other hand, fire prevention effort is highly visible and likely to be favorably received. John Q. can appreciate Smokey Bear and he is likely to feel that fire inspections and fire prevention education are "good things." Thus, in the interest of public relations, if for no other reason, it makes sense for the fire protection service to pay more attention to fire prevention.

There is, however, some evidence that fire prevention dollars pay off in more than public relations. The Report of The National Commission on Fire Prevention and Control supports this, and experience reports published

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1. See Section 3.2.1.

over the last two decades also indicate that such is the case. Also, the number of fire departments reporting increased attention to fire prevention activities appears to be on the rise.

Unfortunately, there is very little policy-related research to assist in management of fire prevention. Only two studies are reported -- the study of arson by Vernon and Bigger [A-60], which was restricted to juvenile arson in the San Diego area, and Miller's study [A-38] of fire inspection management. This paucity of research naturally raises the question, "Why?" We conjecture a few interrelated reasons:

- Difficulty of problems
- Inability to obtain data
- Apparent lack of interest on the part of funding agencies

Problems related to prevention are indeed difficult. Controlled experiments and other efforts to determine the effectiveness of various prevention activities usually require the cooperation of a great many people and may disrupt established, comfortable procedures. Furthermore, in attempts to determine effectiveness, the need to evaluate "what might have been" may arise. There is no good way to do this.

Inability to obtain data is rapidly being remedied by computer-based information systems for fire protection and by readily available census data. Yet, even now, most researchers who attempt to work on fire service problems of any type find that data constitute a problem.

The apparent lack of interest on the part of funding agencies may result from their realization of the difficult nature of prevention-related research. In any event, funding agencies have indicated that the likelihood of useful results from prevention-related research was too low to justify their support of such research. It seems likely that this attitude is now on the verge of change.

The general need for research in fire prevention is clear, and the specific areas most in need of careful study are the following:

- Effectiveness of various prevention activities in terms of loss reduction, as well as cost/effectiveness



- Analysis of fire losses and the implications for prevention activities
- Public education needs
  - media effectiveness
  - type of education most needed
  - population strata to which education should be directed
- Effectiveness of codes and regulations
- Penalties as a deterrent to carelessly started fires
- Use of hazard analysis as a basis for prevention effort allocation

Of all the areas examined in this project, prevention seems to deserve highest priority for research.

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## APPENDIX A

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#### RESEARCH PAPERS SURVEYED

As outlined in Chapter 1, a total of 65 papers and reports were located in the preparation of this report which appeared to deal directly with fire protection service management and to qualify as research. Bibliographical references for each of the documents are provided in this Appendix. Abstracts and evaluations of the reports follow in Appendix B, and Appendix D contains information on how copies of reports can be obtained.

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- A-59. Valinsky, D., "A Statistical Determination of the Distribution and Number of Engine and Ladder Companies in the City of New York," Mayor's Committee on Management Survey, City of New York, 1952.
- A-60. Vernon, R. F. and Bigges, W. R., "The Dimensions of Juvenile Arson and False Fire Alarms for the Urban Areas of San Diego," report of the Urban Observatory of San Diego, San Diego, California, November 1972.
- A-61. Walker, W. E. and Shinnar, S., "Approaches to the Solution of the Fire Engine Relocation Problem," report no. D-19519-NYC, NYC-Rand Institute, November 1969.
- A-62. Will, R. E., "Scalar Economics and Urban Service Requirements; A Method for Determining the Economics of Scale Associated with Municipal Governmental Services, When Offered at Required, Standard Levels, with an Empirical Application to Fire Protection Services," unpublished dissertation, Yale University, 1965.
- A-63. Yahr, H. T., "Aspects of Organization Structure and Organizational Efficiency: A Study of Municipal Fire Departments," unpublished dissertation, New York University, June 1965.
- A-64. "Application of Systems Management Techniques to Fire Protection Operations," final report of a study of Wichita Falls, Texas, Pinnell-Anderson-Wilshire and Associates, Inc., March 1972.
- A-65. "Station Location Model," unpublished report of the Metropolitan Dade County (Florida) Fire Department.

## APPENDIX B

### ABSTRACTS AND EVALUATIONS OF FIRE SERVICE MANAGEMENT RESEARCH PAPERS

As outlined in Chapter 1, a total of 65 reports and papers were collected in the process of this project which could be classified as fire service management research. A bibliography for those research papers is contained in Appendix A. This Appendix provides abstracts and evaluations of the research.

The items provided for each paper (or papers if it was convenient to group two documents reporting the same research effort) are the following:

- Titles: The full title of each of the papers.
- Author(s): The names of each author of the paper(s).
- Reference Number(s): The sequential number(s) used to reference the paper(s) throughout this report.
- Publication Source(s): A bibliographical reference for each paper. Additional information on obtaining copies is contained in Appendices D and F.
- Purpose: A brief statement of the author's purpose or objective in undertaking the reported research.
- Summary: A brief overview of the contents of the paper.
- Abstract: A complete abstract of the work. Questions investigated, assumptions made and results obtained are presented.
- Threats to Internal Validity: The results of the review of the work by the Technical Panel. Methodological errors, invalid conclusions, and misleading results are noted.
- Text Comments on External Validity and Policy Utility: References to sections of the main body of the report where this research is discussed. Such discussions provide

insight on the consistency of the work with other research  
and on the usefulness of the work to fire practitioners.

TITLE: Efficient Allocation of a Quasi-Public Good - Fire Services

AUTHOR: Ahlbrandt, R. S., Jr.

REFERENCE NUMBER: A-1

PUBLICATION SOURCE: Unpublished dissertation, University of Washington, 1972.

PURPOSE: To test the hypothesis that a competitive supplier of fire protection service is more efficient than a bureaucratic monopoly and that the output of the competitive firm will more nearly correspond to public preferences than that supplied by the bureaucratic monopoly.

SUMMARY: Ahlbrandt proposes the hypothesis that the cost of supplying comparable quality-quantity levels of fire protection will be lower for a competitive producer than for a monopolistic producer. To test the hypothesis, a regression cost model is developed for the fire service in King County and Washington State. This model is then used to predict costs for a private competitive producer in Scottsdale, Arizona. The actual costs of the competitive producer were found to be only 50 to 60 percent of the predicted values. Arguments are made that the competitive producer is also more responsive to providing what elected officials prefer than are public fire departments.

ABSTRACT: In order to compare the efficiency of competitively supplied fire service with that of public fire services, the following two corollary hypotheses were examined: (1) the cost of supplying comparable quality-quantity levels of output will be lower for a competitive producer than for a bureaucratic monopoly, and (2) the output supplied by a competitive firm will more closely correspond to preferences of the community than that of a bureaucratic producer

The first hypothesis was examined by developing an empirical cost function for the supply of fire services by bureaucratic monopolies and using this function to predict costs for a competitive supplier. The predicted costs were compared with actual costs.

In developing the empirical cost function, Ahlbrandt obtained data from cities and fire districts in the Seattle-King County area and from some additional cities in the state of Washington. The fire departments studied included 14 operated by all volunteers, 22 by some combination of volunteers and fully paid personnel and 8 manned by fully paid personnel. The basic regression model was specified as follows

$$\ln y = a_0 + a_1 \ln x_1 + a_2 \ln x_2 + a_3 \ln x_3 + a_4 \ln x_4 + a_5 \ln x_5 + a_6 \ln x_6 + a_7 \ln x_7 + a_8 \ln x_8 + a_9 \ln x_9 + a_{10} \ln x_{10} + a_{11} \ln x_{11}$$

$y$  = cost per capita in dollars

$x_1$  = population from 1970 census in 1000's

$x_2$  = area in square miles

$x_3$  = assessed value in millions of dollars

$x_4$  = percentage of housing units lacking all or some plumbing facilities (1970 census data)

$x_5$  = adjusted wage index

$x_6$  = fire insurance rating index

$x_7$  = number of aerial ladder trucks

$x_8$  = number of aid cars

$x_9$  = number of volunteers

$x_{10}$  = number of fire stations

$x_{11}$  = number of full-time personnel

$a_0$  = constant term

$a_1, \dots, a_{11}$  = regression coefficients

Multiple regression was used to estimate coefficients and the results were subjectively analyzed. In addition, Ahlbrandt used the cost function to examine the matter of economies of scale. The following conclusions were reached

- The empirical cost function should not be used to generalize with respect to economies of scale.
- The empirical cost function can be used to predict expected operating costs if two or more communities consolidate.
- The empirical cost function can be used to predict operating costs of existing fire departments.

Ahlbrandt tested the predictive power of the cost model by estimating the costs of supply for bureaucratic monopolies serving five Arizona cities and concluded that it is acceptable. He then used the model to predict the costs for the competitive producer serving Scottsdale, Arizona. The predicted costs were \$7.10 per capita while actual costs were \$3.78 per capita. A statistical test was employed to test the hypothesis that the actual Scottsdale observation came from the same sample as that used to estimate the cost function. The hypothesis was rejected at the 90% level of confidence.

The second corollary hypothesis, the output supplied by a competitive firm more closely corresponds to community preferences than that of a bureaucratic producer, is supported by subjective arguments.

THREATS TO  
INTERNAL  
VALIDITY:

The conclusion that the cost of supplying comparable quality-quantity levels of output will be lower for a competitive producer than for a bureaucratic monopoly cannot be justified by the research. It is true that the results indicate a significant difference between

the Scottsdale costs and the predicted costs. However, there may be reasons for this other than the fact that Scottsdale fire protection is supplied on a competitive basis. This possibility is not adequately examined.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 2.1.1, 2.2.3, 2.2.3.1



TITLE: A Fire Protection Simulation Model for Evaluating Management Strategies.

AUTHOR: Anderson, R. J.

REFERENCE NUMBER: A-2

PUBLICATION SOURCE: Unpublished dissertation, Texas A&M University, December 1970.

PURPOSE: To develop and describe a computer simulation model for evaluation of fire station location, equipment and manpower allocation strategies and strategies of initial alarm response.

SUMMARY: A digital computer simulation model of the fire protection service of Wichita Falls, Texas is described. The model is used to evaluate location, allocation, and initial response strategies. Each of three segments of the simulation model are discussed.

ABSTRACT: Data from Wichita Falls, Texas during the 1964-1968 calendar years were employed in building a simulation model of the city's fire protection service.

NUMBER OF ALARMS

YEAR	GRASS	STRUCTURE	AUTO	TRASH	FALSE	OTHER	TOTAL
1964	747	577	298	139	152	187	2100
1965	595	498	296	105	189	142	1825
1966	681	472	239	124	185	119	1820
1967	1016	474	251	145	144	140	2170
1968	497	482	227	115	120	125	1566
<hr/>							
TOTAL	3536	2503	1311	628	790	713	9481
<hr/>							
% OF TOTAL							
1964	35.6	27.5	14.2	6.6	7.2	8.9	100.0
1965	32.5	27.4	16.2	5.8	10.3	7.8	100.0
1966	37.5	26.0	13.1	6.8	10.1	6.5	100.0
1967	46.8	21.8	11.6	6.7	6.7	6.4	100.0
1968	31.7	30.8	14.5	7.3	7.7	8.0	100.0
<hr/>							
AVERAGE	37.2	26.4	13.9	6.6	8.4	7.5	100.0

The temporal dependence of alarm rates was analyzed by using a non-additive model (alarm rate as a function of hour of the day, day of week and season of year and the various interactions). Statistical significance of each term was assessed by ANOVA and Duncan's multiple range test. Tests did not suggest sequential period alarm rate dependence.

Mappings of occurrence and damage data indicated geographical areas with high and low activity by type of fire; grass, structure, auto, trash and other; allowing the computer program's alarm location segment to separate fires by alarm type.

The data were tabulated by fire damage cost and frequency for each of the aforementioned fire types and the central city area of Wichita Falls was seen to account for the highest damage levels. This damage data also provided the basis for the simulation estimates of loss at each simulated fire.

Response times in the Wichita Falls area were not collected during the 1954-1968 time interval. Response data were collected for the first seven months of 1970, as shown below.

#### RESPONSE TIME IN MINUTES

ALARM TYPE	MAXIMUM TIME	MINIMUM TIME	AVERAGE TIME	TOTAL ALARMS
Grass	25	1	4.3	525
Structure	25	1	3.7	276
Auto	11	1	3.0	96
Trash	14	1	3.7	93
False	17	1	3.0	191

The simulation response times were taken to be 2/100 of an hour plus a computed travel time based upon traveling at an average velocity along the "x" coordinate and then along the "y" coordinate measured from the responding station to the center of the zone of occurrence.

The simulation model functions in three phases:

1. initialization, 2. simulation and 3. analysis.

The initialization phase, in addition to reading and writing descriptive information, simulates the occurrence of stochastic events in accordance with the given alarm mean occurrence values of a particular alarm type via an exponential distribution function, using a {0,1} pseudo random number generator and the inverse transformation of the cumulative distribution function.

Validation of the model consisted of comparison of the temporally generated data and the observed data by a chi square test. Monthly occurrences compared favorably at the 5% level of significance but hourly data did not. Similar chi-square tests for distribution by fire type indicated the model to be adequate.

The simulation phase controls and records the sequence of events of alarm initiation, response strategy, arrival times, damage amounts and accounts for the availability of equipment after completion of service. The analysis phase tabulates alarm occurrence by alarm type and responding section. A typical output is,

# SIMULATION SUMMARY

HOUR OF SIMULATION START=00 DAY OF SIMULATION START=032  
SIMULATION IS TO RUN FOR HOURS OR 028 DAYS OR FOR ALARM OCCURRENCES  
RANDOM NUMBER SEED=4001 NOTE, THIS SHOULD BE 4 DIGIT NUMBER ENDING IN 1  
RESPONSE STRATEGY FOR THIS RUN IS TYPE 2.

## ALARM SUMMARY

THIS ALARM TYPE	TOTAL NBR OF ALARMS	TOTAL DAMAGE AMOUNT IN \$\$	MAXIMUM DAMAGE AMOUNT IN \$\$	AVERAGE DAMAGE AMOUNT IN \$\$	MAXIMUM RESPONSE TIME HR MIN	AVERAGE RESPONSE TIME HR MIN	MAXIMUM ON-SITE TIME HR MIN	AVERAGE ON-SITE TIME HR MIN	AVERAGE MEN ON SITE
GRAS	99	424	9	4	0 17	0 05	0 41	0 24	2.1
STRU	42	1139	98	27	0 10	0 03	0 39	0 25	2.3
FALS	17	0	0	0	0 09	0 03	0 06	0 06	2.8
OTHR	36	855	86	23	0 19	0 04	0 43	0 26	2.4
TOTL	194	2418	98	12	0 19	0 04	0 43	0 23	2.3

## ACTIVITY SUMMARY

THIS STATION NUMBER	NUMBER OF RESPONSES	NBR OF ARRIVALS ON-SITE	TOTAL TIME OCCUPIED HR MIN	NUMBER OF RESP GRASS	NUMBER OF RESP STRUCT	NUMBER OF RESP FALSE	NUMBER OF RESP OTHER	NUMBER TIMES EXTENDED
1	98	39	33 57	43	23	10	22	9
2	82	34	24 40	36	18	11	117	4
3	31	18	12 44	14	7	3	7	0
4	35	25	14 16	14	11	2	8	0
5	69	20	21 47	43	14	4	8	3
6	29	18	13 37	17	7	3	2	0
7	44	40	29 12	31	4	1	8	2
TOTAL	388	194	150 13	198	84	34	72	18

## THREATS TO INTERNAL VALIDITY:

1. Though fairly extensive validation of the model against alarm data was performed, there is no indication of corresponding validation of the other elements more likely to have high impact on the results. Examples are the rectilinear distance approach to calculating response time and the modification of fire losses calculated on the basis of response time.
2. There is no indication of the caution which is always appropriate in producing and interpreting simulation output statistics. One concern is whether the model was allowed to "warm-up" to a steady-state condition before data was taken. Another is the serial correlations in response times and thus fire losses which would likely arise among incidents occurring closely in

simulated time. Such correlations can cause serious overstatements of the accuracy of model results.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 6.4

TITLE: A Comparative Study of Three Municipal Fire  
Departments: An Organizational Analysis

AUTHOR: Arslaner, M. E.

REFERENCE  
NUMBER: A-3

PUBLICATION  
SOURCE: Unpublished dissertation, University of Illinois  
at Urbana-Champaign, June 1972. .

PURPOSE: To develop an understanding of firemen and their  
work and to develop generalizations about organi-  
zational behavior applicable to fire departtments.

SUMMARY: This study examines several personnel and organi-  
zational issues in the fire production service as  
follows:

- The social and political environment  
of fire work
- Formal organization structure
- Recruitment and selection of firemen
- The socialization of firemen
- Firemen's evaluation of their work

The method of approach consisted of surveys  
and interviews conducted with three urban fire  
departments. Based upon an analysis of the  
responses, the author made several tentative  
suggestions for administrative action:

- Improve recruitment and selection of  
fire personnel
- Clarify the bases of inconsistencies  
between the work ethic in American  
society and the requirements of effective  
fire fighting service.

- Make firemen's families, particularly wives, aware of the reasons for work scheduling practices

ABSTRACT:

The performance of fireman's activities entail very little interaction with the public and firemen enjoy a disproportionately low level of social recognition in American society. The role of the fireman has been accorded very little attention by social scientists. Arslaner's study is an attempt to fill that gap.

The study attempts to develop an understanding of organizational behavior by exploring the interdependence of three conceptually distinct levels of analysis of behavior as follows:

- Organizational structure and functioning
- Group composition and interaction
- Individual behavior

The method of approach consisted of case studies, using survey questionnaires and personal interviews, of three urban fire departments.

The analysis of survey responses centered on several important issues as follows:

- The social and political environment of fire work
- Formal organization of municipal fire departments
- Organization for fire fighting
- Recruitment and selection of firemen
- The socialization of firemen
- Firemen's evaluation of their work

Based upon this analysis, the author makes the following observations:

- The prevalence of work ethic in the United States tends to cast the fireman's occupation in an unfavorable light.
- Firemen tend to assume an extremely defensive posture toward probing efforts into their work roles.
- Firemen tend to assign high importance to their occupation.
- Firemen view their work schedules as a constraint on their performance of family and social roles.

As a result of the study, Arslaner recommended administrative action to improve recruitment and selection of firemen and to make firemen's families more aware of the demands of work schedules.

THREATS TO  
INTERNAL  
VALIDITY:

None

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 2.5, 3.1



TITLE: Risk of Fire in Town Centre Developments

AUTHOR: Baldwin, R. and North, M. A.

REFERENCE NUMBER: A-4

PUBLICATION SOURCE: Fire Engineers Journal, vol. 33, p. 38-40, June 1973.

PURPOSE: To assess quantitatively the risks of fires in shopping malls.

SUMMARY: An analysis of the risk of fire in stores located in shopping malls is conducted utilizing a data base compiled by the Board of Trade Census, London, England, for the year 1967. The probability of a fire in a shop occurring in a year; the probability of a fire occurring in a mall of size  $n$  in a year; mean time between fires for a stores' shopping, evening and night hours; the principle sources of shop fire ignition; the probability of a large fire loss exceeding \$10,000; and the fatal accident frequency rate of a shop fire are calculated from this data base.

ABSTRACT: Data compiled by the Board of Trade Census, London, England, for the year 1967 on 5580 fires in 505,000 shops is analyzed. Under the assumption that experience for shops combined in shopping malls will be similar to this data for separately located shops, the following results were obtained:

- (1)  $\text{Pr} \{\text{one fire occurring in a shop in a year}\} = p = 0.01$
- (2)  $\text{Pr} \{\text{at least one fire occurring in a shopping mall of size } n \text{ in a year}\} = 1 - \{1 - p\}^n \approx 0.90$  when  $n = 200$ .
- (3) Mean time between fires for a 200 shop mall by time of day is

- (a) shopping hours = 0.9 years
- (b) evening hours = 1.3 years
- (c) night hours = 3.6 years

(4) Principle sources of ignition for fires will be

	<u>% of fires</u>
Cooking appliances	24
Smoking materials	10
Lighting	9
Wire, cable and leads	8
Domestic appliances	7
Space heating equipment	6
Children and fire	6
Unknown	12
All other sources	<u>18</u>
	100

(5) Given that a fire occurs in a 200 shopping mall,

$$\Pr \{\text{large fire}\} = 0.014$$

$$(a) \Pr \{\text{large fire} | \text{shopping hours}\} = 0.011$$

$$(b) \Pr \{\text{large fire} | \text{evening hours}\} = 0.013$$

$$(c) \Pr \{\text{large fire} | \text{night}\} = 0.030$$

(6) Let  $F$  = number of deaths per person per  $10^8$  exposure hours in shops in shopping malls.

Then  $F_{10} \approx 0.1$  if the average number of people in each shop is 10

and  $F_{100} \approx 0.01$  if the average number of people is 100.

#### THREATS TO INTERNAL VALIDITY:

As the authors recognize, the assumption that experience from shops on an open street can be extended to forecast experience with shopping malls may be troublesome. For example, the inadequate electrical systems and cooking ventilation which often start fires in older buildings may be largely eliminated by improved construction and building codes. On the other hand, the limited

ingress/egress of shopping malls might increase the chances of injury over the level experienced in separated shops.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 5.2.2.2

**TITLE:** Response Areas for Two Emergency Units

**AUTHORS:** Carter, G. M., Chaiken, J. M. and Ignall, E.

**REFERENCE NUMBER:** A-5

**PUBLICATION SOURCE:** Operations Research, vol. 20, pp. 571-594, May 1972.

**PURPOSE:** To investigate the optimal division of a region between primary response districts for two cooperating emergency units.

**SUMMARY:** Given a region B and two fixed positions for cooperating emergency units, the authors characterize the boundary between primary response districts for the units which minimizes mean response time. Implications of such boundaries for the workloads of the two units are also investigated.

**ABSTRACT:** Under the assumptions that

- (1) Calls in each area C of a given region B arise according to a Poisson process with rate  $\lambda(C)$ ;
- (2) The time required by any unit to service an alarm (including travel time in both directions and time at the scene) is independent of the occurrence of alarms and the unit servicing the alarm, and has finite mean  $1/\mu$ ;
- (3) Calls arising in area  $A \subset B$  are serviced by unit 1 if it is available, by unit 2 if unit 1 is busy and unit 2 is free, and by a unit from outside the region if both are occupied;
- (4) Calls rising in area  $(B-A)$  are serviced by unit 2 if it is available, by unit 1 if unit 2 is busy and unit 1 is free, and by a unit from outside the region if both are occupied; and
- (5) The locations of units 1 and 2 are fixed;

areas A which minimize overall response time are characterized. Implications on unit workloads of such optimal assignments of primary response districts are also investigated.

The system is viewed as a Markov process with two servers. States of the system are described by a pair (p,q), with each entry = 1 if the corresponding unit is busy and = 0 if it is free. Using queueing theory, steady-state probabilities  $P_{pq}$  are derived in terms of  $\lambda(B)$ ,  $\lambda(A)$ ,  $\lambda(B-A)$ , and  $\mu$ .

The state where a decision is necessary is (0,0). For this case the mean system response time can be expressed as

$$T_1(A) \frac{\lambda(A)}{\lambda(B)} + T_2(B-A) \frac{\lambda(B-A)}{\lambda(B)}$$

where  $t_i(x)$  = the response time if unit i services a call at point x

$$T_1(C) = \int_{x \in C} t_1(x) d\lambda(x)/\lambda(C)$$

Similar expressions for the other states yield the overall average response time expression

$$\begin{aligned} \bar{T}(A) = & P_{00}[T_1(A) \cdot \lambda(A) + T_2(B-A) \cdot \lambda(B-A)]/\lambda(B) \\ & + P_{01} \cdot T_1(B) + P_{10} \cdot T_2(B) + P_{11} \cdot \tau \end{aligned}$$

where  $\tau$  is the average response time for calls serviced by units from outside the region.

After a lengthy derivation it is shown that this expression is minimized by choosing a set A satisfying  $X \subset A \subset Y$  where

$$X = \{x \in B : t_1(x) - t_2(x) < s_0\}$$

$$Y = \{x \in B : t_1(x) - t_2(x) \leq s_0\}$$

$$s_0 = \rho[T_1(B) - T_2(B)]/(\rho + 1)$$

$$\text{and } \rho = \frac{\lambda(B)}{\mu}.$$

This rule for dividing the region B may admit many different boundaries. However, the common rule of always assigning the closest unit may not be optimal if the alarm rate around one unit's position is greater than that around the other's.

The workload of the two units can be expressed in terms of the steady-state Markov probabilities as

$$w_1 = P_{10} + P_{11} \quad \text{and} \quad w_2 = P_{01} + P_{11}$$

Fixing A and thus  $\lambda(A)$  and  $\lambda(B-A)$  fixes the workloads. Thus, it may be possible to define boundaries between the primary response areas of the two units which improve workload balance without increasing mean response time.

#### THREATS TO INTERNAL VALIDITY:

Under the specified assumptions the development appears correct. However, (as the authors note) the assumption that service times are independent of the state of the system and the location of the alarm may be troublesome. The effect of this assumption is to require that the distribution of service time (which includes travel times) would not change if more distant units were sometimes chosen over the closest units to alarms. Analysis in the paper indicates that weakening of this assumption may tend to make the "assign the closest unit" rule optimal more often.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 5.3.2, 6.1.3, 6.2.2

TITLES:       A Simulation Model of Fire Department Operations:  
              Design and Preliminary Results  
              A Simulation Model of the New York City Fire Department:  
              Its Use in Deployment Analysis

AUTHORS:       Carter, G. M., Ignall, E. J. and Walker, W. E.

REFERENCE  
NUMBERS:       A-6 and A-7

PUBLICATION  
SOURCES:       IEEE Transactions on Systems Science and Cybernetics  
              vol. 6, p. 282-293, 1970.  
  
              Report number P-5110, NYC-Rand Institute, October 1973.

PURPOSE:       To describe and illustrate the use of a discrete  
              event digital simulation model developed in New York  
              City to evaluate alternative policies for positioning,  
              dispatching and repositioning fire suppression forces  
              and equipment.

SUMMARY:       An overview of the design and application of the  
              Rand digital simulation model of the New York City  
              Fire Department is presented. A number of issues in  
              the design and operation of the simulation are discussed,  
              and examples of the use of the model in deployment  
              research are described.

ABSTRACT:       Fire department allocation policies include  
              (1) How many units to send to each incident  
              (2) Which units of each type to send  
              (3) When and which units to relocate in the event  
                  that many units are committed to a series of  
                  working fires  
              (4) Where to locate or relocate fire stations and  
                  companies.  
  
              The simulation discussed in this paper is designed  
              to provide the capability to compare alternatives  
              for such policies. Each policy is symbolically



executed by the computer program on a typical sample of New York alarms and various dimensions of the policy's performance noted.

The model operates in three steps. An input program generates a sample of incoming alarms with attributes (location, seriousness, etc.) drawn from distributions specified by the user. A simulation program then executes the prescribed allocation policy on each incident. The vector of response times of the first, second, etc. companies on the fire scene is recorded for each incident, along with measures of the workload of the various companies. Post-simulation analysis programs analyze the results of the simulation phase and compare alternative policies. The input and simulation programs are in SIMSCRIPT I.5, and post-analysis programs are in FORTRAN.

A number of methodological issues in the design of the simulation are discussed in detail. One is the appropriateness of the vectors of suppression unit response times as a surrogate measure of loss of life and destruction of property. It is concluded that this vector is adequate so long as one policy dominates in all components, but that resolution is difficult when dominance does not occur.

A second issue is the way analytical models of the deployment situation motivate alternative policies to be considered in the simulation. While most situations simulated are too complex to be solved analytically, analytical approximations are shown to be very instructive.

Finally, a "virtual measures" technique is proposed to collect data on rare event policies such as relocation.

In the process of simulating other policies, this technique interrupts processing to make a "virtual observation" by asking "what would happen if the rare event occurred while the system was in its present state?".

Applications of the model reported in these papers use data developed from experience in the Bronx. Rates of occurrence of seven different incident types, including false alarms and various types of emergencies and fires, were determined from 1968 data.

In each reported application study a proposed allocation policy was simulated and compared to the simulated response of the current policy to the same set of alarms. The policies investigated include

- (1) Adding several extra companies at fire houses where heavy workloads were being experienced and modifying dispatch policies to send fewer units to alarms not likely to be serious
- (2) Implementing a scheme for relocating companies into areas without protection on the basis of a computer algorithm
- (3) Revision in working hours of firemen at some firehouses to make possible the manning of extra apparatus during the peak evening hours, while leaving some houses unattended during the unbusy, early morning hours.

In each case results showed the proposed policies to be superior to the current procedures.

THREATS TO  
INTERNAL  
VALIDITY:

The principal omission in these papers is evidence that the results produced by the simulation model are comparable to the actual response experience in New York City. Extensive data collection was apparently

performed, but no validation of the simulation model  
or results is reported.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 5.4.2, 6.4

TITLE: New York City Fire Alarm Prediction Models I: Box-Reported Serious Fires

AUTHORS: Carter, G. and Rolph, J.

REFERENCE NUMBER: A-8

PUBLICATION SOURCE: Report no. R-1214-NYC, NYC-Rand Institute, May 1973.

PURPOSE: To develop and compare statistical estimators of the probability that an alarm from a particular box signals a serious fire.

SUMMARY: Using data on fire-box-reported alarms in New York City during 1967-69, a series of statistical estimators are developed for the probability that an alarm from a given box signals a serious fire. The estimators are then compared with respect to their accuracy in predicting 1970 experience and their efficiency in computer simulation tests of fire dispatch policies using the estimators.

ABSTRACT: In order to provide necessary inputs for fire dispatching decision rules (See [A-10] and [A-55]), the authors investigate a number of estimators of

$P(S/i)$  = the probability that an alarm  
from box  $i$  signals a serious  
alarm.

For this purpose a serious alarm is defined to be any fire in an occupied structure that requires at least four fire companies of any type, or one engine and two ladder companies. Thus an alternative, "two-stage" approach to estimating  $P(S/i)$  is derived through conditional probability as

$$P(S/i) = P(S/0,i) P(0/i)$$

where  $P(S/0,i)$  = the probability an alarm from box  $i$  signals a serious alarm given that it is in an occupied building.

$P(0/i)$  = the probability an alarm from box  $i$  signals a fire in an occupied building.

Two direct, "one-stage" estimation models and two two-stage models are considered. Model I is a box history model considering only experience with a particular box. The estimator is given by

$$\hat{P}_I(S/i) = z_i/n_i$$

where  $z_i$  is the number of serious fires in occupied structures signaled by the  $n_i$  alarms reported through box  $i$ .

Model II is a second one-stage procedure which employs empirical Bayes estimation with a binomial prior distribution estimated over the one of four large regions  $R$  that includes box  $i$ . The estimator is given by

$$\hat{P}_{II}(S/i) = \frac{z_i + \beta_R q_R}{n_i + \beta_R}$$

$$\text{where } z_R = \sum_{i \in R} z_i$$

$$n_R = \sum_{i \in R} n_i$$

$q_R$  is approximately  $z_R/n_R$  and  $\beta_R$  is determined from the data.

Models III and IV use the two-stage approach.  $P(0/i)$  is estimated first. Comparison of four different empirical Bayes approaches for combining experience at box  $i$  with experience from a relatively small surrounding neighbor-

hood of k boxes led to selection of the estimator

$$\hat{P}(0/1) = (1 - \hat{B}_1)x_1 + \hat{B}_1\bar{x}$$

where  $x_1$  = the historical fraction of alarms from box i  
which signal fires in occupied buildings

$\bar{x}$  = a weighted sum of such experience at boxes  
 $i = 1, 2, \dots, k$

and  $\hat{B}_1$  is a factor indicating how much the estimate  
should depend on  $X_1$ .

The second stage of Models III and IV use a binomial-  
empirical Bayes estimate  $\hat{P}_B(S/0,i)$  and a constant over  
the region estimate  $\hat{P}_C(S/0,i)$  respectively to estimate  
 $P(S/0,i)$ . Expressions for false estimates are given by

$$\hat{P}_B(S/0,i) = \frac{z_i + \alpha_R p_R}{y_i + \alpha_R}$$

$$\hat{P}_C(S/0,i) = \frac{z_R}{y_R}$$

where  $y_i$  = the number of fires in occupied structures  
reported from box i

$$y_R = \sum_{i \in R} y_i$$

$p_R$  is approximately  $\hat{P}_C(S/0,1)$  and  $\alpha_R$  is estimated from  
the data.

Using data on fire box alarms in the Bronx during 1967-  
1969, the estimators were compared on the basis of likeli-  
hood ratio tests on their prediction of 1970 experience.  
This analysis showed Model I inferior, but the others  
nearly equal.

In a second analysis Models I, II, III, and IV were used  
in computer simulation tests of the use of the estimators  
in dispatch decision rules. In these tests Models III

and IV appeared superior but nearly equally effective. Thus the computationally simpler Model IV was selected.

A second part of the paper investigated the effect of region, season, and hour of the day on  $P(S|1)$  with the same data base. Logit regression equations are used to estimate such effects. This analysis concludes that these effects are just as well estimated on a large regional basis.

THREATS TO  
INTERNAL  
VALIDITY:

The statistical techniques of this paper appear sound, but it is not always clear why particular techniques are chosen. For example, it is not clear why logit rather than the simpler, linear regression was used in the final part of the paper.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 6.2.1

TITLE: New York City Fire Alarm Prediction Models II:  
Hourly Alarm Rates in Small Regions

AUTHOR: Carter, G. M. and Rolph, J. E.

REFERENCE NUMBER: A-9

PUBLICATION SOURCE: Report no. WN-8288-NYC, NYC-Rand Institute, June 1973

PURPOSE: To develop a prediction model for forecasting fire alarm rates in small areas of a city.

SUMMARY: The authors develop a methodology for predicting the alarm rate of serious fires in a small area using data collected in the Bronx from 1964 to 1969. Various other quantities are estimated, such as the daily alarm rates in large regions and hourly alarm rates, and combined to form estimates of the rate of occurrence of serious fires in any given small area. Factors include the trend over time, season, day-of-the-week, hour-of-the-day, and weather.

ABSTRACT: Various policy decisions are based on forecasts of fire occurrences. Dispatching decisions, relocation rules, and fire company placement require estimates of fire rate in small regions. Factors such as season, day-of-the-week, hour-of-the-day, and weather may affect this rate. This paper uses data from the Bronx from 1964 to 1969 to estimate the rate of serious fires in a given small region over a given period of time. The fires are assumed to occur as a Poisson process; the variable estimated being the parameter of this distribution.

The forecasting approach pursued involves a sequence of estimation stages. First a procedure was developed to predict the number of alarms on



each day in each of the four relatively homogeneous hazard regions which make up the Bronx. Second, the fraction of alarms occurring at each hour of the day in each region was estimated. Application of this fraction to the predicted daily alarms yields a basic forecast for the given hour and region. A smoothing step then is applied to adjust the basic forecast for short term increases and decreases in the alarm rate.

The development of the appropriate mathematical expression for each of these stages was accomplished with a variety of regression techniques. Alternative mathematical forms were proposed, and necessary parameters for each was estimated from 1964-69 data. The "best" forms were then selected on the basis of the accuracy with which they forecast 1970 experience.

In the process of this analysis, the authors report reaching the following conclusions:

- Best regression results are obtained when the number of alarms in an area and time is estimated by using its square root as the response variable. In particular, estimating the square root of the number of alarms is superior to either estimating the number of alarms directly or estimating the logarithm of the number of alarms.
- Estimation of the square root of the daily number of alarms requires terms to adjust for a long term trend, day-of-the-week, and week-of-the-year.
- Daily alarm patterns on Monday through Thursday are essentially the same, but all other days produce different patterns. Thus four different day-of-the-week effects must be included in the

expression for the daily alarm rate (weekdays, Friday, Saturday, and Sunday).

- Separate parameter estimates are required for each hazard area because of variations in both the number and pattern of alarms.
- Estimation of individual types of alarms separately and summing to yield total alarms does not significantly improve the quality of the estimates over those obtained by working directly with total alarms.
- Explicit adjustment for weather conditions is not necessary in forecasting alarms if short term variations in alarms are provided for via smoothing.
- Estimation of the fraction of alarms occurring in any hour requires adjustment for day-of-the-week and week-of-the-year. However, the week-days (Monday through Thursday) have a single pattern of variation.

The final form of the selected model for the rate of alarms on each day and region is

$$f(x_{ijk}) = \beta_1 j + \beta_2 E(j) + \sum_{k=2}^4 \left( a_k \sin \frac{k\pi j}{26} + b_k \cos \frac{k\pi j}{26} \right) + \sum_{m=1}^4 D_{im} \left( C_m + A_m \sin \frac{\pi j}{26} + B_m \cos \frac{\pi j}{26} \right)$$

$$\text{where } D_{im} = \begin{cases} 1 & \text{if the } m\text{th day pattern is} \\ & \text{appropriate for day } i \\ 0 & \text{otherwise} \end{cases}$$

$x_{ijk}$  = the number of alarms occurring in day  $i$  of week  $j$  in region  $k$

$f(x_{ijk})$  = the estimate of  $\sqrt{x_{ijk}}$

$$E(j) = \begin{cases} 1 & \text{if } j \geq 209, \text{ i. e. the period falls} \\ & \text{after a discrete jump in 1968} \\ 0 & \text{otherwise} \end{cases}$$

and all other variables are parameters to be estimated from the data. The estimate of  $x_{ijk}$  is then

$$\hat{x}_{ijk} = f(x_{ijk})^2$$

Similarly, the chosen model for the fraction of the alarms in day i, week j and region r that occurred in hour h is

$$y_{rijh} = c + \sum_{\ell=1}^2 \left[ a_{0\ell} + a_{1\ell} (j^2 - 52j) + a_{2\ell} (j^3 - (52)^2 j) \sin \left( \frac{\pi \ell h}{12} \right) + (b_{0\ell} + b_{1\ell} (j^2 - 52j) + b_{2\ell} (j^3 - (52)^2 j) \cos \left( \frac{\pi \ell h}{12} \right) \right]$$

The regions here are as large as an entire borough and thus consist of one or more of the regions denoted by k above.

Combining these two estimation stages, the number of alarms in region r, hour h, day i and week j,  $P_{rijh}$ , is estimated by

$$\hat{P}_{rijh} = \hat{Y}_{rijh} \sum_k \hat{X}_{ijk}.$$

where the summation is over all regions k included in the larger region r. When forecasting is for the immediate future, exponential smoothing is

used to improve this estimate by capturing the effect of weather and other independent variables not treated explicitly. Using this smoothed estimate the total alarm rate predictions in any small area  $c$ ,  $a_{cijh}$ , is obtained as a fraction of the rate of region  $r$  (which contains  $c$ ) where the fraction is the ratio of the number of alarms in area  $c$  to the number of alarms in region  $r$  in the last two years.

Finally, the probability that a given alarm is serious is estimated. Bronx-wide data is used. Three seasons are considered--June to September, December to March, and a single Spring/Fall season. Each day is divided into three parts: 0-8 A. M., 8 A. M.-4 P. M., and 4 P. M. to mid-night. Nine periods result. Using two independent variables for the time of day, two for season, four interaction variables, a linear time trend variable, and a dummy variable for a sudden use in the data due to the 1968 unrest, a linear model is fit using logit regression.

The estimate that a given alarm in area  $i$  is serious is

$$\hat{\mu}_{it} = \frac{e^{L_{it}}}{1 + e^{L_{it}}}$$

where

$$L_{it} = \hat{\beta}_{0i} + \sum_{j=1}^{10} \hat{\beta}_j x_j (1970, t)$$

and the

$$x_j(k, t)$$

provide the coefficient matrix of the model.

THREATS TO  
INTERNAL  
VALIDITY:

While the statistical details are omitted at many points, the reasoning appears sound throughout most of the paper. However, errors do occur. For example, at one point the authors state

"If  $X$  is a random variable with mean  $\mu$  and  $P = (X)^{\frac{1}{2}}$ , then

$$\text{Var}(P) = E(P^2) - E^2(P)$$

$$E(X) = E(P^2) = E^2(P) + \text{Var}(P)$$

Thus if  $\hat{p}$  is an unbiased estimate of  $E(p)$ , then  $\hat{p}^2 + \text{Var}(P)$  is an unbiased estimate of  $E(X)$ ."

The reasoning is incorrect since

$$E(\hat{p}^2 + \text{Var}(P)) \geq E(X)$$

Mistakes of this sort matter little if the estimates of alarm rates and of the probability of serious fires are accurate. Unfortunately, the authors make evaluation of the accuracy somewhat difficult.

There is widespread use of the  $R^2$  statistic, a measure called "worth," and standard errors, but the authors do not provide a simple comparison of 1970 actual rate versus 1970 predicted rate for the twenty-four small areas. They do compare observed versus predicted probabilities of serious fires, although only at an aggregate level.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 5.2.1

TITLE: Simulation Tests of Fire Department Initial Dispatch Strategies

AUTHORS: Carter, G. and Swersey, A. J.

REFERENCE NUMBER: A-10

PUBLICATION SOURCE: Report no. WN-8335-NYC, NYC-RAND Institute, August 1973.

PURPOSE: To report the results of simulation experiments with alternative policies for deciding how many units to dispatch to incoming fire alarms.

SUMMARY: The "How many to dispatch?" decision rule developed by Swersey [A-55] is slightly extended and tested using Rand's digital simulation of the New York City Fire Department (see [A-6, A-7]). Results indicate that dispatching rules which consider the availability of units in the area surrounding the alarm and the probability that the alarm signals a serious fire improve system performance.

ABSTRACT: In [A-55] Swersey developed a policy for whether to dispatch one or two companies to an alarm which considered the following factors:

- (1) The probability that an alarm signals a serious fire,
- (2) The number of companies available in the area surrounding the alarm,
- (3) The alarm rate in the area surrounding the alarm,
- (4) The weight or relative importance assigned to the response time of the first, as opposed to that of later-arriving companies at the fire scene,
- (5) The workload of the companies in the area surrounding the alarm.

The rule is based on the principles that the cost of sending one unit when two are needed is the increased response time of the second unit associated with the need for the first unit to reach the scene and call for help; and that the cost of sending two units when only one is required is increased company workloads and decreased response time to new alarms occurring while the unnecessary second unit is unavailable.

The rule sends two units if the first of these costs is greater, and sends one otherwise. Thus it makes sending two companies more likely as (1) and (2) increase, and less likely as (3), (4) and (5) increase.

In this paper the authors report simulation experiments with two versions of Swersey's decision rule. One version of the rule is the one originally proposed by Swersey, where company availability is evaluated in terms of the number of free units in the fixed region which includes the alarm. The second considers availability in the "dynamic area" consisting of the N closest company locations to the alarm. Comparison runs were also made using the present New York City policy and some arbitrary policies designed to provide insight about the proposed policies. All runs simulated the operation of the fire department in the Bronx in a period with an average alarm rate of 30 per hour.

Results indicate the proposed policy using dynamic areas is superior to that with fixed areas, and both are superior to the present New York City policy.

Most of the gain appears to have resulted from consideration of the probability that an alarm is serious in the proposed decision rules and not in the present policy. However, consideration of company availability also contributes to the improvement.

THREATS TO  
INTERNAL  
VALIDITY:

1. The contrived dispatch policies used for comparison do provide information about the importance of the various elements of the decision rule. However, there appears to be no reason why a more standard crossed experimental design could not have been used. The result would probably have been more clear indications of the effects of various components of the rule with no significant increase in computational effort.
2. Various differences are reported as "statistically significant" in the paper, but no details are provided on the source of such statistical conclusions. In particular, there is no indication of whether the problem of serial correlations in company response times discussed in [A-6] was adequately handled.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 6.2.1



TITLE: The Number of Emergency Units Busy at Alarms Which Require Multiple Servers

AUTHOR: Chaiken, J. M.

REFERENCE NUMBER: A-11

PUBLICATION SOURCE: Report no. R-531-NYC/HUD, NYC-Rand Institute, March 1971.

PURPOSE: To develop mathematical expressions which describe the steady-state probability that given numbers of emergency units are busy.

SUMMARY: The probability that a given number of emergency units will be busy is studied under the assumptions that calls for services arise according to a mixture of Poisson processes, and that service of each process occurs in a number of independent stages with finite-mean service-time distributions. Each stage corresponds to a particular number of units busy at the call. Mathematical expressions are derived for the steady-state distribution of this probability, and the usefulness of the expressions in allocating emergency service resources is discussed.

ABSTRACT: The author models the urban emergency service environment as a queueing system where

- (1) Calls arise according to a mixture of  $\ell$  independent Poisson processes with intensities  $\lambda_1, \lambda_2, \dots, \lambda_\ell$
- (2) Service for each type of alarm  $i$  occurs in a sequence of independent stages corresponding to the  $(2n_i + 1)$  periods when  $1, 2, \dots, n_i - 1, n_i, n_i - 1, \dots, 1$  of a maximal force of  $n_i$  units are assigned to the call
- (3) The distribution of holding time in any stage  $j$  of the service process for the  $i$ th type of

alarm is arbitrary with finite mean  $T_1(j)$ ,  
and independent of both the alarm process and  
the state of the system

- (4) The total number of servers in the system is  
infinite.

Under these assumptions he investigates the distribution of the total number of units busy.

This distribution is of interest as a tool in determining how many emergency units to assign to a given region. The probability that any particular number will be inadequate can be directly calculated from the results in the paper.

The author recognizes that the assumption of independence of the various random variables in the system may be troublesome. For example, the assumption that stage service-times are independent of the state of the system implies the distribution of response time, which is a part of the service time for each assigned unit, is unaffected by the number of units busy at alarms. Similarly, the assumptions imply the distribution of times in various stages of service are uncorrelated, even though, for example, the early departure of the  $n_1$ th unit (end of stage  $n_1$ ) might imply a longer period to departure of the  $(n_1 - 1)$ st unit (stage  $n_1 + 1$ ).

Within these limitations, the author applies standard, multi-dimensional queueing approaches to derive an expression for the steady-state probability  $P(m)$  that  $m$  total units are busy. For  $m = 0$ ,

$$P(m) = e^{-r},$$

and for  $m > 0$

$$P(m) = e^{-r} \left[ \rho(m) + \frac{1}{2!} \rho^{*2}(m) + \dots + \frac{1}{m!} \rho^{*m}(m) \right]$$

$$\text{where } \rho(j) = \sum_{i=1}^{\ell} \rho_i(j)$$

$$\rho_i(j) = \begin{cases} \lambda_i(T_i(j) + T_i(2n_i - j)) & \text{if } j=1, \dots, n_i-1 \\ \lambda_i T_i(n_i) & \text{if } j = n_i \\ 0 & \text{otherwise} \end{cases}$$

$$r = \sum_j \rho(j)$$

and the notation  $*k$  denotes the  $k$ -fold convolution.

THREATS TO  
INTERNAL  
VALIDITY:

None were observed.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 6.1.3

TITLE: Coalescence of Municipal Police and Fire Services:  
A Comparison of Experience in the United States,  
Canada, and Great Britain

AUTHOR: Cunningham, W. M.

REFERENCE A-12  
NUMBER:

PUBLICATION Unpublished dissertation, Claremont Graduate School  
SOURCE: and University Center, 1968.

PURPOSE: To examine the history of efforts to combine the functions  
and administration of police and fire protection  
services.

SUMMARY: The matter of police-fire integration (coalescence)  
has caused considerable controversy for many years.  
This study is an in-depth analysis of experience  
with integration of municipal police and fire services  
in the United States, Canada, and Great Britain.  
The method of approach consists of literature study,  
personal correspondence, and interviews with fire  
service and municipal leaders in cities where some level  
of police-fire coalescence has been attempted. Experiences  
are compared and conclusions are drawn concerning  
efficiency, economy and effectiveness of the combined  
services.

In Great Britain, coalescence of municipal police and  
fire services is specifically forbidden by Section 32  
of the Fire Services act of 1947, and the study finds  
a trend in the U. S. toward limitation or abolition of  
coalescence. With regard to efficiency of combined  
services, there is no definitive conclusion. However,  
the British experience tends to indicate that efficiency  
of the coalesced system is in many aspects a variable

dependent upon the size and population of the city in question.

The matter of comparative economy in coalesced systems is difficult to analyze. However, in comparison of cost analyses in the British and American experiences, the study finds evidence that there is no great economy in coalescence. No city is known to have reduced its total budget for the two services through adoption of coalescence. The cost of returning to separate services, after a period of coalescence, appears to be very high.

With regard to the effectiveness of coalesced services, the study finds that such systems do not perform well under severe and continuing ecological demands. The British experience indicates that service is poorest when needed most.

The general result of this comprehensive study is that there is a probable trend toward the ultimate complete abolition of coalescence in the municipalities of the United States.

THREATS TO  
INTERNAL  
VALIDITY:

The study is very thorough and well documented. However, interpretation and comparison of many experiences with coalescence is subjective. It is not at all certain that another researcher, looking at the same facts, would draw identical conclusions.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 2.3.2, 3.3.1

TITLE: Allocation of Emergency Ambulances to Fire Stations  
A Methology for Emergency Ambulance Deployment

AUTHOR: Fitzsimmons, J. A.

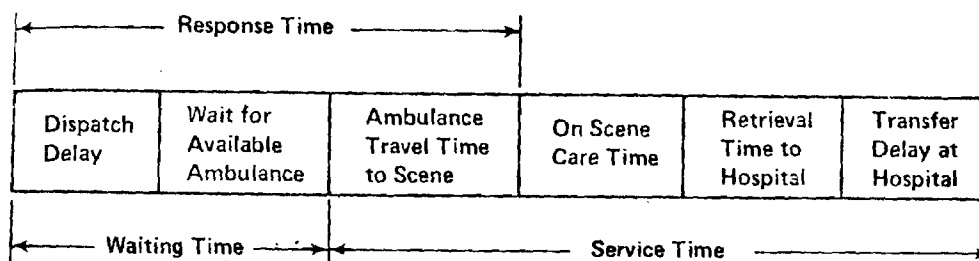
REFERENCE NUMBERS: A-13 and A-14

PUBLICATION SOURCES: Fire Technology, vol. 9, p. 112-118, May 1973.  
Management Science, vol. 19, p. 627-636, Feburary 1973.

PURPOSE: To propose a procedure for positioning ambulances in an urban area in such a way as to minimize expected response time to emergency calls.

SUMMARY: A combined analytic and Monte Carlo procedure is developed for estimating the expected ambulance response time associated with a given positioning of ambulances. Hooke and Jeeves' search technique is then employed to vary the positions until expected response time is minimized. Application of the procedure in Los Angeles is discussed.

ABSTRACT: The complete sequence of events associated with an ambulance's service to a patient includes all the elements shown in the following figure.



Since this sequence includes relatively long travel times and other delays which take ambulances out of service, and since there may be relatively few ambu-

lance in a city, the author argues a stochastic optimization procedure is appropriate for selecting the optimal positions at which to station ambulances. A procedure is developed which employs both analytic and Monte Carlo simulation elements in minimizing the expected response time.

If it is assumed that alarms arise according to a Poisson process and that the probability of having no ambulances available is negligible, that the number of ambulances available can be viewed as a  $M/G/\infty$  queueing system. For a mean alarm rate,  $a$ , and mean service time,  $1/s$ , the distribution of the number of units busy is known to be Poisson with rate  $a/s$ . In the ambulance case this rate can be expressed by

$$\frac{a}{s} = a(\bar{R} + RET + C)$$

where  $\bar{R}$  is the mean response time of the system,  $RET$  is the mean retrieval time for moving from the emergency location to a hospital, and  $C$  is the mean on-scene delay time plus the mean transfer time at the hospital.

In this research, the expected time  $\bar{R}$  is calculated for a given set of ambulance positions as the sum of the probabilities that various numbers of ambulances are busy times the conditional expected response times of the system given the number busy. Under the above assumptions, the desired probabilities are Poisson, and the conditional response times for different numbers of units busy can be estimated by Monte Carlo simulation. However, the expected value being calculated,  $\bar{R}$ , is part of the mean defining the required Poisson probabilities. This difficulty is dealt with by recursively estimating  $\bar{R}$  and using the estimate to produce new estimates of the Poisson probabilities until the value of  $\bar{R}$  stabilizes.

Using this combined analytic and Monte Carlo approach to estimating the mean response time for each set of positions, the author's procedure systematically varies the positions until  $\bar{R}$  is minimized. Hooke and Jeeves' search technique is employed.

Details of the application of the procedure to positioning ambulances in Los Angeles are discussed. The search was initiated at a heuristically-determined "good positioning" and allowed to seek an optimum. Results showed the optimum locations produced a 8.6% reduction in expected response times as compared to the present heuristically-derived positions.

THREATS TO  
INTERNAL  
VALIDITY:

1. Not enough details are provided to know the accuracy with which Monte Carlo results were estimated. A stochastic search procedure like the one proposed always has a probability of terminating before optimality is reached. Insufficient accuracy of the Monte Carlo results would increase the likelihood of such premature termination.

2. Though many of the details of the statistics used in applying the procedure to Los Angeles are omitted, some of those presented suggest minor methodological errors. For example, the Kolmogorov-Smirnov test is inappropriately used to test the fit of a discrete probability distribution.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 6.1.3



TITLE: Cost-Effectiveness in Fire Protection

AUTHORS: Gordon, B. B., Drozda, W. and Stacey, G. S.

REFERENCE NUMBER: A-15

PUBLICATION SOURCE: Report of project numbers 355-8038 and 355-8031, Battelle Memorial Institute, December 1969.

PURPOSE: To outline preliminary approaches to the application of cost-effectiveness analysis in fire protection.

SUMMARY: Results are reported from an exploratory study of the application of cost-effectiveness analysis to problems of fire protection. Types of analysis addressed include estimation of marginal costs of fire protection, determination of the nature of marginal benefits of fire protection, use of detailed fire data as management information, and computer simulation of proposed operational changes. All analysis is performed using data from Dayton, Ohio.

ABSTRACT: In this report the results are reported on a preliminary, exploratory study of the application of cost-effectiveness analysis to fire protection. Data from Dayton, Ohio is used as an illustration.

The first analytical problem addressed is the estimation of the incremental costs of fire protection programs. Procedures are proposed for estimating manning costs, equipment costs, fire station costs, and other costs. Short-term cost items are estimated directly, and longer investments are dealt with via equivalent annual series.

In a second portion of the report, the authors discuss the problem of estimating the benefits of fire protection programs. Benefits accruing from changes in insurance premiums, reduced property loss, and reduced loss of life are discussed. No estimation methodologies are

proposed, although the effect of response time on these benefits is hypothesized.

A third segment of the analysis reports results of a brief study of operating data from the Dayton, Ohio Fire Department. A total of 2,156 fire runs made during the last six months of 1968 were analyzed. Significant variations in alarm rates were observed at different times of the day, but no significant day-of-the-week effect could be identified.

A simulation model was developed as the final element of this exploratory study. The model reproduces the alarm input noted in the previous analysis of fire reports, and moves units to and from the fire scenes. However, no application of the model is discussed.

THREATS TO  
INTERNAL  
VALIDITY:

The authors' intent was only to produce an exploratory analysis, and many of the details of that analysis are not provided in the report. Thus, detailed technical criticism of the work is neither appropriate nor possible.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 2.1.2, 2.2.2, 6.4

TITLE: A Fire Station Placement Model

AUTHORS: Guild, R. D. and Rollin, J. E.

REFERENCE NUMBER: A-16

PUBLICATION SOURCE: Fire Technology, vol. 8, pp. 33-44, February 1972.

PURPOSE: To propose a simple analytic model for determining the number of fire suppression companies to assign to a given region which minimizes expected total fire cost.

SUMMARY: A simple analytic model is developed for determining the expected cost of a decision to assign a particular number of fire units to a given region. The model expresses expected cost in terms of the number of units assigned to the region, the area of the region, the density of fire calls, the velocity of vehicles in the area, and the relation between the cost of providing fire forces and the cost of fire losses. The optimal solution to the model is reduced to tabular form.

ABSTRACT: A simple analytic model for determining the expected total cost of assigning a given number of fire suppression units to a given region is developed under the following assumptions:

- After  $n$ , the number of units to be assigned, is chosen, the units will be placed optimally in the region, with each unit serving a sub-region of size  $A/n$ .
- The suppression unit assigned to each sub-region services all calls arising in the sub-region. If this unit happens to be busy when the call arrives, the call is delayed until the unit becomes free.
- Response time to fire calls is in direct proportion to response distance.

- Fire calls arise according to a Poisson process with equal intensity  $\lambda_T$  per week over the entire region.
- Work times of fire units at the scene of fire calls are exponentially distributed with mean  $1/\mu_p$  hours.

With these assumptions the expected societal cost per fire associated with stationing  $n$  units in the region (denoted  $c(n)$ ) is given by

$$c(n) = \left\{ \begin{array}{l} \text{Expected cost per} \\ \text{fire of maintain-} \\ \text{ing } n \text{ units} \end{array} \right\} + \left\{ \begin{array}{l} \text{Cost per} \\ \text{hour of} \\ \text{burning} \end{array} \right\} \left\{ \begin{array}{l} \text{Expected wait-} \\ \text{ing time due to} \\ \text{the primary unit} \\ \text{being busy when} \\ \text{needed} \end{array} \right\} \\ + \left\{ \begin{array}{l} \text{Expected travel} \\ \text{time to and from} \\ \text{the fire scene} \end{array} \right\} + \left\{ \begin{array}{l} \text{Expected service} \\ \text{time at the fire} \\ \text{scene} \end{array} \right\}$$

By obtaining the expected waiting time from results for the M/G/1 queue, the expected travel distance from elementary location theory, and estimating other components of the expression directly,  $c(n)$  can be calculated as

$$c(n) = \frac{168 C_f n}{\lambda_T} + C_v \left\{ \frac{\frac{\lambda_T}{168n} \left[ \left( \frac{A}{6nv^2} + \frac{1}{\mu_p^2} \right) + \left( \frac{A^{1/2}}{n^{1/2}v} + \frac{1}{\mu_p} \right) \right]^2}{2 \left[ 1 - \frac{\lambda_T}{168n} \left( \frac{A^{1/2}}{n^{1/2}v} + \frac{1}{\mu_p} \right) \right]} + \left( \frac{A^{1/2}}{n^{1/2}v} \right) + \left( \frac{1}{\mu_p} \right) \right\}$$

where  $A$  = area of the region in square miles

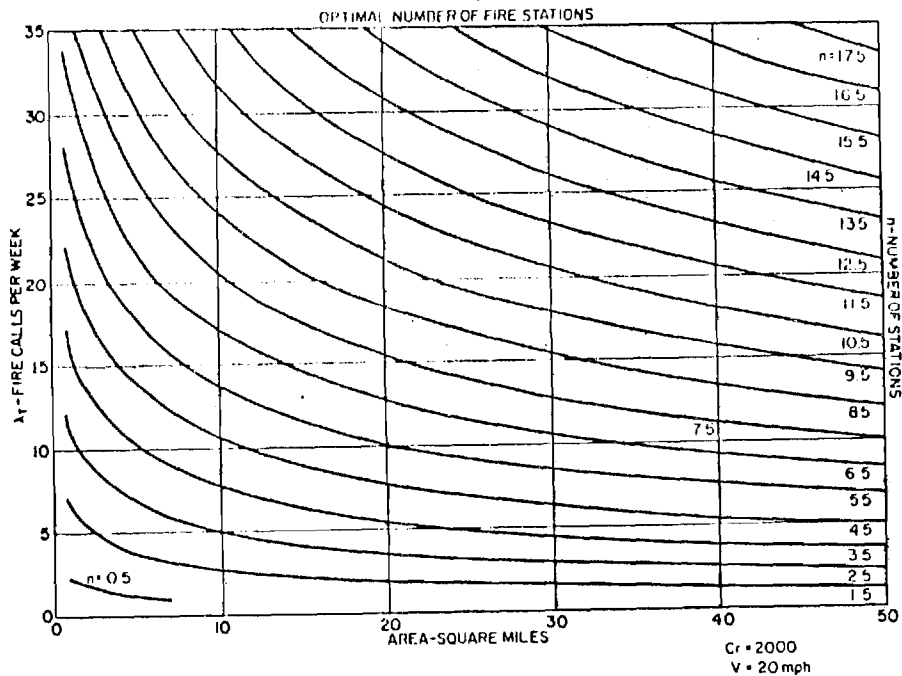
$v$  = average velocity of the fire truck between the station and the location of the fire, in miles-per-hour

$C_f$  = average fire facility cost in \$/hour

$C_v$  = average cost of fire burning in \$/hour

$$C_r = C_v / C_f$$

Equal expected cost curves for various parameter values are then plotted to indicate the best choice for the number  $n$ . An example is given below.



THREATS TO  
INTERNAL  
VALIDITY:

The model depends upon some very strong assumptions, but the development from these assumptions appears correct.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 5.3.4, 6.1.1

TITLE: The Perceived Involvement of Fire Department  
Offices: Operational and Management Functions

AUTHOR: Hickey, H. E.

REFERENCE  
NUMBER: A-17

PUBLICATION  
SOURCE: International Fire Administration Institute report,  
State University of New York at Albany, October 1969.

PURPOSE: To investigate the degree to which various fire  
department officers perceive themselves to be involved  
in management functions and activities.

SUMMARY: A detailed survey was administered to a sample of  
fire department officers in order to determine the  
extent to which these officers perceived themselves  
to be involved in management functions. The survey  
results were analyzed for several strata of officer  
level (e. g. Chief of Dept., company officers, etc.)  
and for various population groupings. The general  
conclusions of the study are (1) fire department  
officers consider themselves to have a high level of  
involvement in management functions, (2) they perceive  
their involvement as not in accordance with modern  
organizational objectives, and (3) educational programs  
for fire officers should provide for growth in  
professional management activities.

ABSTRACT: Although the purpose of the study was to determine  
how fire department officers perceived their own  
involvement in management activities, the underlying  
motivation was to determine the educational needs  
of fire officers. The study was conducted by means  
of a detailed survey questionnaire mailed to fire  
officers of American cities according to population.

The questionnaire was designed to solicit from these officers their perception of the proportion of time spent in the following management activities:

- Organizing
- Planning
- Directing
- Coordinating
- Controlling
- Communicating

Survey responses for each question, each population group, each department type, and each officer rank was tabulated and discussed. In addition, a series of weighted sums of responses to different questions were calculated to produce indices of perceived involvement.

Results from the more general indices suggest that most fire officers perceive a high degree of involvement in various management functions. Thus the author suggests that better training of fire officers in management techniques may be in order.

THREATS TO  
INTERNAL  
VALIDITY:

It is not clear from the paper whether the author intended his results to be scientifically verifiable. If he meant the results to be technically valid several difficulties are obvious:

- (1) There are no indications of tests of the survey to be sure that persons understood questions in the same way.
- (2) The sample appears inadequate for any statistical inferences because returns in some strata were quite small and biased toward one or two city's practice.

- (3) No more than heuristic justification is given for the calculations used in the indices of perceived involvement.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 3.1



TITLE: The Supply of Urban Public Services

AUTHOR: Hirsch, W. Z.

REFERENCE NUMBER: A-18

PUBLICATION SOURCE: Issues in Urban Economics, edited by H. Perloff and L. Wingo, Johns Hopkins Press, 1968.

PURPOSE: To develop an understanding of factors involved in supplying urban public services. In particular to explore production functions, costs and cost functions, and scale economies.

SUMMARY: This study explores the supply side of urban public services. Particular factors studied were

- Urban public service production
- Urban public service costs and cost functions
- Economies of scale
- Supply questions
  - Who should supply urban services?
  - How should they be distributed?

ABSTRACT: This report deals with the general subject of the supply of urban public services. The output quantity of a tangible public service is defined by a "basic service unit" (e. g. for fire protection: a city block protected from fire). Each such service unit tends to have numerous quality dimensions which make the measurement of quality an extremely difficult undertaking. As a result it is common practice to use output quality proxies. Output quality proxies for fire protection are square miles covered per pumper company, population covered per pumper

company, and average number of building fires per first due pumper company.

A variety of proxies are also used for output quality value and total output value. These are shown in the table below.

---

PROXIES FOR OUTPUT QUALITY, OUTPUT QUALITY VALUE, TOTAL OUTPUT VALUE

---

*I. Output quality*

- a. Samples of one, or few, output quality characteristics.
- b. Absolute input quantities.
- c. Relative input quantities.
- d. Input performance indicators.

*II. Output quality value*

- a. Value of one, or few, output quality characteristics, valued in terms of benefits.
- b. Value of one, or few, output quality characteristics, valued in terms of cost.
- c. Output quality or any of its proxies
- d. Input costs.

*III. Total output value*

- a. Output value in terms of the benefits of one, or few, quality characteristics.
  - b. Output value in terms of the cost of one, or few, quality characteristics.
  - c. Output quality value or any of its proxies
  - d. Output quality or any of its proxies
  - e. Input costs.
  - f. Physical output performance indicators.
- 

Empirical production functions and empirical cost functions for urban public services are discussed. An example is the average unit cost function for fire protection of the St. Louis City-County area in 1955-56.

$$X_1 = 0.63 - 0.000\ 0235X_2 + 0.000\ 000\ 000\ 109X_2^2 - 0.0866X_3 \\ + 0.000\ 00170X_4 - 0.00206X_5 - 0.000\ 0108X_7 \\ + 1.889X_9 + 0.00231X_{10},$$

where the following are notations

$X_1$  = per capita total current expenditures plus that service for fire protection,

$X_2$  = nighttime population,

$X_3$  = area in square miles,

$X_4$  = density of dwelling units per square mile,

$X_5$  = 1950-55 nighttime population increases,

$X_7$  = combined receipts of wholesale, retail, and service establishments,

$X_8$  = number of wholesale, retail, and service establishments,

$X_9$  = index of scope and quality of police protection,

$X_{10}$  = average per capita assessed valuation of real property.

The report discusses theoretical considerations of scale economies and proceeds to test the theoretical hypotheses by examining results of a few empirical studies.

The report further discusses the supply of urban public services and service distribution by income, race, and community. These discussions are largely expository.

THREATS TO  
INTERNAL  
VALIDITY:

The report does not contain sufficient detail to evaluate internal validity.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 2.2.3

TITLE: Some Policy Implications for Improved Measurement of  
Local Government Service Output and Costs: The Case of  
Fire Protection

AUTHOR: Hitzhusen, F. J.

REFERENCE A-19  
NUMBER:

PUBLICATION Unpublished dissertation, Cornell University, 1972.  
SOURCE:

PURPOSE: To develop empirical models of various elements of the  
social costs of fire protection which are suitable for  
investigating important economic issues in fire protection  
policy.

SUMMARY: Drawing primarily on data from Texas and New York, four  
empirical models are constructed which express the total  
social cost of fire protection per unit of service pro-  
vided as a function of the quality of the service and a  
number of social and economic factors. The models are  
then used to investigate certain broad policy issues in  
fire protection.

ABSTRACT: In a first analysis, social costs, including operating  
and capital costs for fire departments, estimates of the  
value of volunteer efforts in fire departments, costs of  
water systems allocatable to fire protection, and fire  
insurance premium costs; were estimated for both Texas  
and New York. The author undertook extensive data collec-  
tion and analysis to estimate each of these cost elements  
for a representative sample of communities. Increasingly  
more comprehensive sums of these components were then  
divided by the total population or property protected to  
estimate a set of costs per unit of service. Regression  
analysis was used to relate these dependent variables to  
the quality of the fire protection service (as measured  
by the American Insurance Association Grading Schedule)

and a number of peripheral social and economic variables. Comparison by community size showed that unit costs tend to decrease as the total population or protected property increases, i.e., economies of scale were observed.

A second analysis attempted to investigate the tradeoff between public investment in fire protection service and private insurance savings. The public costs and insurance premium benefits of a number of fire service changes were estimated and expressed in cost-benefit ratios. Particularly in Texas, the results show insurance benefits of many fire service improvements are greater than the cost of the improvements.

A final analysis attempted to compare the effects of the quite different insurance rate fixing schemes used in Texas and New York in terms of overall fire losses. The results of this analysis appear to prove the Texas system more conducive to loss reduction, apparently because the Texas method depends much more directly on fire losses in the area being rated.

THREATS TO  
INTERNAL  
VALIDITY:

None were observed.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 2.1.1, 2.2.2, 2.2.3, 3.2.2

TITLE: A Distribution Model for an Emergency Service

AUTHOR: Hogg, J. M.

REFERENCE NUMBER: A-20

PUBLICATION SOURCE: Unpublished masters thesis; Management Engineering Section, University of London, September 1970.

PURPOSE: To develop a procedure for determining the number and positions of fire companies in a city which minimizes total social cost.

SUMMARY: A procedure is developed which determines the optimal number of fire stations, and selects among alternative locations and company contingents for the stations, on the basis of minimizing the total cost to society. The procedure is then applied to the problem of locating fire stations in Glasgow, Scotland as it is expected to appear after extensive reconstruction in the 1980's.

ABSTRACT: The total cost to society of a particular set of fire stations  $i=1, \dots, m$  and company contingents  $k_i$  for each of these stations is expressed as

$$z = \sum_{i=1}^m (f_i + p(k_i)) + \sum_{j=1}^n g(\min_i \{d_{ij}\})$$

where  $f_i$  = the cost of building station  $i$  and providing it with one company  
 $p(k_i)$  = the cost of providing an additional  $(k_i - 1)$  companies for station  $i$   
 $t_{ij}$  = the response time from station  $i$  the demand node  $j$   
 $g(t)$  = the function expressing fire losses in terms of response time

A procedure is then developed for estimating each element of this cost, and a variant of Beale's enumerative, tree-search scheme is used to select an optimal number of stations, optimal station locations (from among a fixed set), and optimal contingents of companies for each station.

Costs of providing stations and companies were estimated from very rough data available from the U. K. Home Office. A distinction was made between costs for downtown and costs for suburban locations.

Travel times between points were calculated as the shortest time path through a rough network representation of the anticipated 1990 Glasgow street pattern. Times on each link were determined from travel speeds forecast by city planners, and a shortest path algorithm was then applied to calculate the travel time between all pairs of nodes.

The relationship between fire losses and response time is determined on the basis of Hogg's earlier model of fire spread (see [6-18]). Application of the model produced empirically validated (nonlinear) functional relationships between loss and response time for several different classes of fires and structures. The expected number of Glasgow fires in each such category was forecast for every demand node on the basis of regression on residential and working population. Total losses at each node could then be determined by applying the empirical relationships to the forecasted number of fires and the response time of the closest company in the allocation plan being evaluated.

The computational procedure did not give satisfactory solution times for moderately large problems. Some feasible solutions had to be eliminated from consideration

(thus possibly producing sub-optimal solutions)  
in order to cause the algorithm to terminate within  
available computer resources.

THREATS TO  
INTERNAL  
VALIDITY:

1. This thesis uses rather complex calculations on roughly estimated parameters to select company locations. It would certainly seem that both better documentation of the statistical validity of these estimates and investigation of the sensitivity of results to the estimates could have been appropriate. Moreover, less complex estimation schemes might well have provided satisfactory results with much less computational effort.
2. The computational efficiency of the proposed procedure is clearly unsatisfactory. Warehouse location algorithms, developed since this research was performed, could significantly reduce computation times.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 5.1.1, 5.1.3, 5.3.4, 6.1.2



TITLE: Planning for Fire Stations in Glasgow in 1980

AUTHOR: Hogg, J. M.

REFERENCE NUMBER: A-21

PUBLICATION SOURCE: Fire Research Report no. 1/68, U. K. Home Office Scientific Advisory Branch, October 1968.

PURPOSE: To develop a set of fire station locations for Glasgow, Scotland as it is expected to appear in 1980 after massive redevelopment.

SUMMARY: The problem of choosing among a feasible set of fire station locations and determining the number of fire companies to be assigned to each location is addressed. A procedure which minimizes expected response time is developed and applied to Glasgow, Scotland as it is expected to appear in 1980.

ABSTRACT: The number of pumper companies to be assigned to Glasgow in the 1980's will depend on a number of economic considerations not modeled in this research. To deal with this limitation, a plan is developed for each possible number of pumper truck locations.

Such districting plans are chosen by an enumeration procedure which seeks to minimize expected response time from chosen stations to fire calls. For this purpose the city of Glasgow was divided into a number of fixed districts and the mean travel time from each potential station site to each district estimated from a simulation procedure.

Considerable discussion is presented on the estimation of necessary parameters for the simulation model. In particular; travel speeds of fire engines, the relation between Euclidean distance and true distance traveled, and the effects of assuming that all fire calls in a

district occur at its center of gravity are discussed in some depth.

THREATS TO  
INTERNAL  
VALIDITY:

- (1) The optimization procedure is not documented well enough to determine whether it is an exact or a heuristic method. However, it appears that if the procedure is exact, then any of the better known warehouse location algorithms would be more efficient; and if it is heuristic, the author's continual use of the words "optimal" and "best" is inappropriate.
- (2) In the parameter estimation efforts reported in the paper a great deal of data is presented, but no statistical analysis is given. Thus, it is impossible to make any statements about the reliability of the expected response times used in the optimization. Moreover, much of the data is suspect because it is derived from experience in the 1960's and used in an analysis of a completely reconstructed city of 1980.
- (3) The description of the simulation used to calculate expected response times is too vague to be evaluated properly. However, there are indications that the probability a call is answered by the nearest pumper, second nearest, etc. was treated as independent of the total number and positioning of pumper trucks. Such an assumption could clearly not be justified except as an approximation.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 5.1.3, 6.1.2

TITLE: The Siting of Fire Stations

AUTHOR: Hogg, J. M.

REFERENCE NUMBER: A-22

PUBLICATION SOURCE: Operational Research Quarterly, vol. 19, p. 275-287, Sept. 1968.

PURPOSE: Given  $n$  possible sites for locating fire stations to determine the best location of  $r=1,2,3,\dots$  stations and identify the primary subarea each station should serve.

SUMMARY: Given  $n$  possible fire station sites the limit on fire appliances that each station can hold, and data on the demand on these services, the paper deals with a method of obtaining the optimal location of  $r=1,2,3,\dots$  stations to minimize total travel time and also the allocation of subareas to these stations. The important conclusion is that beyond a certain optimum point, it is not desirable to increase the number of fire stations.

ABSTRACT: This paper deals with the location of fire stations in Bristol, U. K.. The question of how many ( $r$ ) and which of  $n=19$  potential sites should be chosen to optimize overall response time.

The area to be served was first subdivided into  $m=15$  subareas such that there was sufficient demand for fire services within each subarea, there was at least one potential site within each subarea, the boundaries followed topological features such as rivers and railway lines, and areas along boundaries were low fire incidence areas.

Data used in the procedure included

$t_{ij}$  = travel time from the  $i$ th station to the "centre of gravity" of the  $j$ th subarea for  $i = 1, \dots, n$ ;  
 $j = 1, \dots, m$  and

$f(k|j)$  = frequency of demand for a  $k$ th appliance in subarea  $j$ .

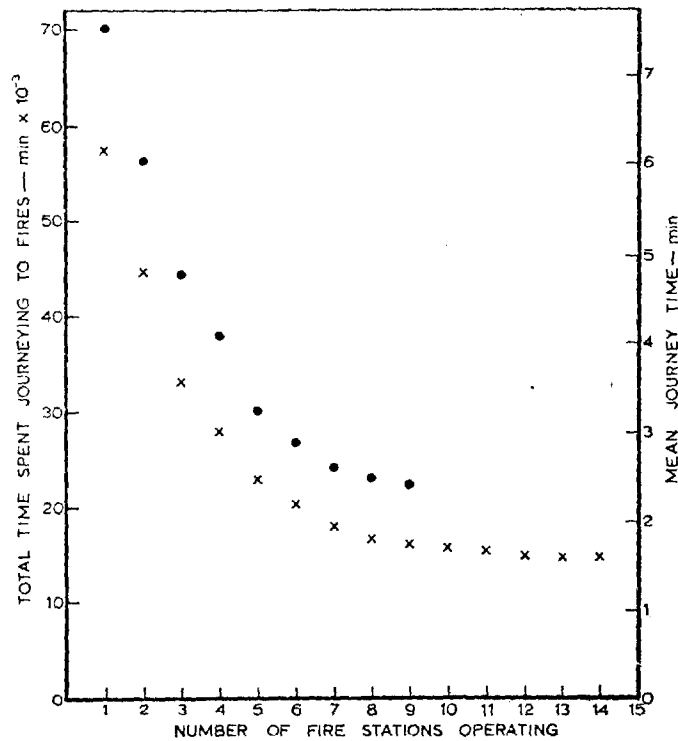
Travel times were estimated from experience when station  $i$  already existed, and by field experiments for proposed station locations. Historical data and projected growth in each subarea were considered in developing  $f(k|j)$ .

The number of trips between station  $i$  and area  $j$  is generated using the  $t_{ij}$  values and the maximum number of appliances each site could handle. If a demand called for  $k$  fire appliances and the nearest site can handle up to  $c < k$  appliances,  $c$  of the demand is allocated to the nearest station and  $(k-c)$  is allocated to the next to nearest station. The aggregation of calls thus allocated gives the demand  $d_{ij}$  from each site to each subarea. The total time taken on all appliance journeys is then estimated as

$$T \cdot D = \sum_{i=1}^n \sum_{j=1}^m t_{ij} d_{ij}$$

The calculation is repeated by excluding each of the  $n$  sites in turn. The minimum of the  $n$  problems gives the least cost allocation if  $(n-1)$  of the  $n$  possible sites are used. The procedure is repeated for each combination of  $(n-2)$  sites,  $(n-3)$  sites and so on.

For the Bristol example considered, the plot of total travel time vs. the number of stations is as given in the figure below. It will be observed that after 6 sites are selected the journey time decreases only marginally. Hence, the additional cost of an additional station is not likely to offset the gain from reduced fire damage due to reduced travel time.



THREATS TO  
INTERNAL  
VALIDITY:

1. As the author notes the allocation scheme for calculating the  $d_{ij}$  is correct only if the closest units are almost always available to respond to any alarm. If these "first choice" units are not almost always the ones actually servicing alarms, more distant units would be assigned and the total T·D would increase. Thus the results probably underestimate the response time which would actually be observed with a given set of stations.
2. The author explains a number of 2 for 1, 3 for 2, etc. trades searched for in choosing  $r$  stations for  $r \leq n-2$ . However, there is not enough detail provided to determine whether the resulting stations are in fact the optimal  $r$  or merely a heuristic approximation.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 5.1.3, 5.3.4, 6.1.2

TITLE: Station Siting in Peterborough and Market Deeping

AUTHOR: Hogg, J. M.

REFERENCE NUMBER: A-23

PUBLICATION SOURCE: Fire Research Report No. 7/70, U. K. Home Office Scientific Advisory Branch, November 1970.

PURPOSE: To analyze alternatives for the siting and manning of fire stations in the Peterborough and Market Deeping area of the United Kingdom.

SUMMARY: A procedure developed by the author in [A-20] is applied to the analysis of alternatives for the siting and manning of fire stations in the Peterborough and Market Deeping area of the United Kingdom. Necessary cost and response time inputs to the procedure are estimated, and the combinations of stations and station manning which minimize estimated cost to society are determined for various total numbers of stations.

ABSTRACT: In this paper the author applies a procedure developed in an earlier work [A-20] to the problem of positioning fire stations in the Peterborough and Market Deeping area. For a given total number of stations, that procedure selects the combination of fire stations which minimizes an estimate of the total cost to society. Total cost includes the estimated cost of providing the fire stations and an estimated cost of fire losses obtained from empirically derived functions of response times. Response times are, in turn, calculated as the minimum time paths through rough network representations of the street pattern in the region of interest.

For the Peterborough and Market Deeping case 25 geographic points were considered. Fire incidence at each point is determined on the basis of regression

on working and residential populations. Travel times along links in the street network connecting these points are estimated on the basis of designed speeds of the street system adjusted for the degradation experienced during peak traffic hours. Cost data are obtained by direct analysis of recent experience.

Allowing each of the 25 points to be a potential station site, the optimal sites were selected for 3,4,...,11 total stations. Results showed that the minimum cost was obtained with 4-5 stations if stations were manned by permanent forces.

THREATS  
TO INTERNAL  
VALIDITY:

1. The limitations of the author's optimization procedures are discussed in the comments on reference [A-20].

2. As in the Glasgow case of [A-20], more analysis of the sensitivity of optimal solutions to variations in cost estimates would seem appropriate. A rather large number of only roughly-determined parameters underlie each siting plan selection.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 5.1.3, 5.3.4



TITLES: Response Areas for Fire-Fighting Units-Application  
Response Areas for Groups of Fire-Fighting Units I-  
Theory

AUTHOR: Ignall, E.

REFERENCE A-24 and A-25  
NUMBERS:

PUBLICATION Draft working paper, NYC-Rand Institute, March 1974.  
SOURCES: Report no. WN-7561-NYC, NYC-Rand Institute, October 1971.

PURPOSE: To develop policies for determining which of the avail-  
able companies should be assigned to respond to a given  
alarm after the question of how many to send has been  
resolved.

SUMMARY: Earlier work in Carter, Chaiken, and Ignall [A-5] on  
which of two cooperating units to dispatch to an alarm  
is extended to provide insight into which group of N  
available units in a region should be dispatched. A  
linear programming formulation of the problem is de-  
veloped, and a solution identified for the case where the  
objective is to minimize response time. Simulation experi-  
ments with an application of this solution in New York  
City are also discussed.

ABSTRACT: A model of the "Which units to dispatch?" problem is  
formulated under the following assumptions:

- (1) A group N of a possible 2N units is to be chosen
- (2) Alarms arise at a finite set  $\Omega$  of points x, in  
m = 1, 2, ..., M ways (box, telephone, etc.), and  
according to independent Poisson processes with  
rates  $\lambda(x, m)$
- (3) The N units dispatched all complete work simul-  
taneously after a "service time" with mean  $1/\mu$   
which is independent of the units chosen and the  
alarm generation processes

- (4) The utility of a particular policy is a function of the resulting response times and company workloads.

Expressions for the mean response time in this model are derived, and the selection of a "which" policy is formulated and (partially) solved as a linear program.

Under the above assumptions, the only time at which there is a decision to be made is when an alarm arises while all  $2N$  units are available. The effect of a decision at these times will carry through until all units are again free, i.e., through one queueing-theoretic busy period. By conditioning on  $K$  = the number of alarms served during the busy period, the author shows that the mean response time implied by a decision to send the units in a set  $A$  is given by

$$TR = \left[ t_A(x,m) + (T_{A'})\alpha + \frac{(T_A + T_{A'})\alpha^2}{2(1-\alpha)} \right] \left[ \frac{\mu}{\lambda + \mu} \right]$$

where  $t_C(x,m)$  is the utility of sending units in a set  $C$  to an alarm at point  $x$  reported by method  $m$

$$T_C = \frac{1}{\lambda} \sum_{x \in \Omega} \sum_m t_C(x,m) \lambda(x,m), \text{ i.e., the mean}$$

utility of sending the units in  $C$  to any alarm

$$\lambda = \sum_{x \in \Omega} \sum_m \lambda(x,m), \text{ i.e., the overall-alarm rate}$$

$$\alpha = \frac{\lambda}{\lambda + \mu}$$

and  $A'$  = the set compliment of  $A$ .

To develop an optimal policy for choosing  $A$ , the author then defines policy variables

$$y_G(x,m,A) = \text{the probability that under policy } G, \\ \text{units in } A \text{ are assigned to an alarm} \\ \text{arising at } x \text{ and reported by } m.$$

Assuming these variables are non-negative and satisfy

$$\sum_A y_G(x, m, A) = 1 \text{ for all } x \text{ and } m, \quad [1]$$

the response time criterion corresponding to a policy G is

$$T(G) = \frac{\mu}{\lambda(\lambda + \mu)} \sum_x \sum_m \sum_A \lambda(x, m) y_G(x, m, A) \left\{ t_A(x, m) + T_{A, \alpha} + \frac{(T_A + T_{A'}) \alpha^2}{2(1 - \alpha)} \right\} \quad [2]$$

From other work [6-11] the probability unit j is working is known to be expressible as

$$W_j = (\rho_j + \rho^2 + \rho^{3/2}) / [(1 + \rho)(1 + \rho + \rho^2/2)] \quad [3]$$

$$\text{where } \rho_j = \frac{1}{\mu} \sum_x \sum_m \sum_A \lambda(x, m) y_G(x, m, A) I(j, A)$$

$$\rho = \frac{\lambda}{\mu}$$

$$\text{and } I(j, A) = \begin{cases} 1 & \text{if } j \in A \\ 0 & \text{otherwise} \end{cases}$$

If it is desired to keep differences in these workloads  $\leq \delta$  then constraints

$$W_j - W_k \leq \delta \quad \text{for all } j \neq k \quad [4]$$

can be added. The resulting policy selection problem is the linear program

$$\min_G a_1 T(G) + a_2 \delta$$

subject to [1], [2], [3], and [4], where  $a_1$  and  $a_2$  are the weights placed on response time and workload balance respectively.

If zero utility is assigned to workload balance the term  $T_A + T_A$ , in [2] is independent of A. The author uses this fact to show that the above linear program can be solved trivially in this case. The optimal policy is equivalent to choosing companies to respond to an alarm at x reported by m in ascending order of the criterion

$$t_j(x,m) + \theta_j f_m$$

where  $f_m = 1 + (r - 1) \text{Pr} [\text{an alarm by } m \text{ is serious}]$   
 $r$  = the ratio of the value of response to serious  
 versus non-serious alarms  
 and  $\theta_j$  = a workload balancing factor derived from [3].

Application of this criterion in a simulation of activity in the Bronx is also discussed. Results showed some improvement in workload balance but no significant change in response times when the proposed policy is compared to present dispatch policies.

THREATS TO  
INTERNAL  
VALIDITY:

- (1) The studies include a number of minor notational and typographical errors, but that is not unexpected in working papers.
- (2) Under the stated assumptions, the development appears correct. However, the assumptions are rather severe, and thus the work should not be considered a complete answer to the "which" problem.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 5.3.2, 6.2.2

TITLE: A Model for Predicting Average Fire Engine Travel Times

AUTHOR: Kolesar, P.

REFERENCE NUMBER: A-26

PUBLICATION SOURCE: Unpublished memo, NYC-Rand Institute, April 1974.

PURPOSE: To propose and test a simple empirical model for predicting the mean response time of fire companies assigned to a given region in terms of the area of the region and the number of units assigned.

SUMMARY: The author motivates and tests the model

$$ET = \alpha + \beta \left( \frac{A}{n - \lambda ES} \right)^{\gamma}$$

as an estimator of the expected response time ET of n units, assigned to a region of area A, alarm rate  $\lambda$ , and expected service time per alarm ES. On the basis of comparisons to response data produced by Rand's computer simulation of the New York City Fire Department, the model appears to provide a satisfactory estimator.

ABSTRACT: Earlier work by Kolesar and Blum [A-27] used a combination of theoretical and empirical evidence to argue that the mean response distance, ED, of a set of n units serving a region with area A, alarm rate  $\lambda$ , and mean alarm service time ES could be effectively approximated by

$$ED = k \sqrt{\frac{A}{n - \lambda ES}}$$

where k is a constant of proportionality.

Other work by Kolesar and Walker [A-28] used theoretical arguments and field data to argue that response time T

could be expressed in terms of distance D as

$$ET = \begin{cases} 2\sqrt{\frac{ED}{a}} & \text{if } ED \leq 2d_c \\ \frac{v_c}{a} + \frac{ED}{v_c} & \text{if } ED > 2d_c \end{cases}$$

where  $a$  is the rate of acceleration of emergency vehicles and  $v_c$  is the constant cruising emergency velocity reached by units after a distance  $d_c$  has been traveled.

In this paper the formulas developed in these two earlier works are combined to produce the relationship

$$ET = \begin{cases} c_1 \left( \frac{A}{n - \lambda ES} \right)^{\frac{1}{4}} & \text{if } ED \text{ is "small"} \\ c_2 + c_3 \left( \frac{A}{n - \lambda ES} \right)^{\frac{1}{2}} & \text{if } ED \text{ is "large"} \end{cases}$$

where  $c_1$ ,  $c_2$ , and  $c_3$  are constants to be estimated. The hypothesized model is then tested against simulation results derived from Rand's computer simulation of the New York City Fire Department (See [A-6] and [A-7]). Response time is estimated in the simulation by

- (1) Estimating distance via an empirical expression with inputs of the orientation of the street grid and the coordinates of the alarm and the responding company
- (2) Using Kolesar and Walker's estimators defined above to convert distance to time

Thus, there is some similarity between the simulated and tested estimation procedures.

Letting  $\bar{T}$  be the mean response time of the closest ladder company, and  $\bar{N}$  be the mean number of units busy in the region, the simulation analysis showed that the form

$$\bar{T} = \beta \left( \frac{A}{N} \right)^{\gamma}$$

provided an adequate fit to the data ( $r^2 \geq .9$ ). The best estimates of  $\beta$  and  $\gamma$  were approximately 2.0 and 0.3 respectively. Thus, since the distances simulated were generally short, results of the simulation experiments do tend to confirm the hypothesized statistical relationship. The author argues that the linear part of the estimating relationship could be expected to perform as well for longer runs.

THREATS TO  
INTERNAL  
VALIDITY:

1. Since the computer simulation itself estimates response time in a way similar to the hypothesized procedure, comparison of hypothesized and simulated results cannot be considered adequate validation of the estimating relationship.
2. Not enough details are provided to permit evaluation of the statistical procedures used to calculate  $r^2$ , etc. or to determine whether appropriate techniques were used to deal with the problems of serial correlation, etc. which arise in analysis of simulation statistics.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 5.4.4, 6.1.1

TITLE: Square Root Laws for Fire Engine Response Distance

AUTHORS: Kolesar, P. and Blum, E. H.

REFERENCE NUMBER: A-27

PUBLICATION SOURCE: Management Science, vol. 19, p. 1368-1378, August 1973.

PURPOSE: To arrive at a means of predicting average response distance for emergency units in a region based on readily measurable parameters such as the number of units and the area.

SUMMARY: The authors hypothesize that the expected response distance for a group of emergency service units serving a region varies as  $\sqrt{A/n}$ , where  $n$  is the number of units and  $A$  is the land area of the region. The robustness of this assertion is tested analytically under rather restrictive assumptions and statistically, on simulated data, under far more realistic assumptions.

ABSTRACT: Suppose there are  $n$  firehouses to serve a region of area  $A$ . The authors hypothesize that the expected response distance  $D$  from these firehouses is given by  $D=K/(n/A)^{1/2}$  where  $K$  is a constant of proportionality.

This hypothesis is first tested against some analytic models derived from the case where demand is homogeneous over the region. It is supposed that emergency units are located at random (i.e. according to a two dimensional Poisson process with density  $\rho = n/A$ , for large  $A$ ). that all units  $n$  are available, and that incidence of fires is homogeneous in the region. Let  $R_k$  be a random variable denoting the Euclidean distance from an arbitrary point to the  $k$ th nearest emergency unit. It can be shown that the expected value of  $R_k$  is given by

$$E(R_k) = K\rho^{-1/2}$$



where  $K$  is a constant (depending on  $k$ ). The probability that a given response distance, say  $r$ , is exceeded is

$$\exp(-\pi p r^2)$$

which decreases exponentially with the value of  $n$ .

In the dynamic case, where all the  $n$  units are not available, the long-run average response distance is studied. Let  $X(t)$  be a  $n$ -vector denoting the state of the system at time  $t$ . The  $i$ th component of  $X(t)$  describes the state of unit  $i$ ; e.g., idle, responding to fire, etc. If the occurrence of fires is according to a Poisson process with alarm rate  $\lambda$ , and if service times are mutually independent and are exponentially distributed with mean  $1/\mu$  whenever units are available, the system becomes a  $M/M/n$  queuing system. In this case, the expected long-run distance  $E(R(n))$  can be approximated by

$$E(R(n)) \approx K/(n-\gamma)^{\frac{1}{2}} \quad \text{where } \gamma = \frac{\lambda}{\mu}.$$

The above models included the restrictive assumptions that service was geographically homogeneous and stationary in time and that service times were independent of system state. To deal with these limitations, the authors also report testing the square root relationship via simulation under more realistic assumptions. The simulation model (see [A-6] and [A-7]) generates alarms for incidents of various types and severity according to projections of historical patterns under which alarm rates vary significantly throughout the region. Complicated decision rules for dispatching and relocation of fire engines are used. The relationships observed were

- (1) The relation between expected response distance  $E(R(t))$  and  $N(t)$  where  $R(t)$  are random samples denoting response

distance and  $N(t)$  are the units available at time  $t^0$ ,  
and

(2) The long-run form of this same relationship.

Results show the  $\bar{R}(t) = E(R(t)) = \alpha_1 / (N(t))^{1/2}$  is a good fit with simulated data. Further,  $\bar{R} = E(R(t)) = \alpha_2 / \bar{N}^{1/2}$  is also a good fit where  $\bar{N} = E(N(t))$ .

A final section of the paper discusses the application of the "square root" formula in emergency unit resource allocation problems. Under the assumption that response time is a linear function of response distance, procedures are outlined for both minimizing expected response subject to a limit on the number of units available, and minimizing the number of units required to achieve an acceptable mean response time.

THREATS TO  
INTERNAL  
VALIDITY:

None were observed.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 6.1.1

TITLE: Measuring the Response Characteristics of New York City's Fire Companies

AUTHORS: Kolesar, P. and Walker, W. E.

REFERENCE NUMBER: A-28

PUBLICATION SOURCE: Draft report no. R-1449-NYC, NYC-Rand Institute, December 1973.

PURPOSE: To empirically investigate the relationship between response time and response distance of fire vehicles in New York City.

SUMMARY: For a sample of 1700 responses by New York City fire vehicles, the relationship between response time and response distance is investigated. Principle results indicate response time grows in proportion to the square root of response distance for trips of up to 1-2 miles and in proportion to response distance for longer runs.

ABSTRACT: During the summer of 1971 a number of companies of the New York City Fire Department carefully recorded their travel distances and travel times to fire calls. A total of 1772 responses of 13 companies were recorded.

Using this data the authors fit and compare various approaches to estimating response times from response distances. The following three functional forms,  $T(D)$ , for estimating time from distance  $D$  were considered:

- (1)  $T(D) = c\sqrt{D}$
- (2)  $T(D) = a + bD$
- (3)  $T(D) = gD^h$

After separately estimating the constants in these

relationships for each company and comparing the fit of the results, the authors concluded

- The square-root relation, (1), provides the best fit to the data for short runs (up to 1 mile)
- The linear relation, (2), provides the best fit to data for longer runs
- Variations in parameter estimates for different parts of the city are small enough that a single empirical model could suffice for the entire city.

On the basis of these conclusions the authors recommend the relationship

$$T(D) = \begin{cases} 3.05 \sqrt{D} & \text{if } D \leq 1.2 \text{ miles} \\ 1.67 + 1.39D & \text{if } D > 1.2 \text{ miles} \end{cases}$$

A supplemental analysis investigated whether response velocity is affected by time-of-day. Results showed that only slight variations from the city-wide average of 18.3 miles-per-hour were experienced, with velocity slowest during the morning rush hour.

THREATS TO  
INTERNAL  
VALIDITY:

In this analysis the authors had available a considerable amount of apparently reliable empirical data. Thus, there is no apparent reason for the intuitive, heuristic methods the authors use to reach statistical conclusions. In several cases where the authors used a "common sense" guess to compare the fit of various models, well-known hypothesis testing procedures would have been more appropriate.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 5.1.3, 6.1.1

TITLE: An Algorithm for the Dynamic Relocation of Fire Companies

AUTHOR: Kolesar, P. and Walker, W. E.

REFERENCE NUMBER: A-29

PUBLICATION SOURCES: Report no. R-1023-NYC, NYC-Rand Institute, September 1972.

PURPOSE: To develop an on-line computer procedure by which fire companies can be relocated from time to time so that all points have at least a minimum level of service and the costs associated with relocation are minimized.

SUMMARY: A procedure is developed which will

- (1) Identify areas which temporarily do not have adequate fire protection
- (2) Identify possible relocations to overcome inadequacies found in (1) while taking into consideration total response time
- (3) Choose relocations which minimize total time involved in relocation.

ABSTRACT: The problem attacked is to find a method of relocation of fire services (engine or ladder companies), so that each fire alarm represented by alarm boxes can be attended. The level of service that is assumed necessary to maintain is that at least one of the closest three units to each box be available. Similar statements can be made for engine and ladder companies. The relocation refers to the movement of free units (companies) into firehouses whose engines are busy attending fires.

The authors' procedure is implemented in four basic steps, the last three are discussed in detail below.

- (1) Identification of uncovered response neighborhoods.  
A response neighborhood is the set of alarm boxes which have the same three closest engine locations.  
The identification is done by a periodic search to

see whether all three closest engines are busy for each fire alarm box.

- (2) Determination of empty houses to be filled to cover all alarm boxes.
- (3) Determination of the available units to relocate.
- (4) Reallocation of free units to cover all alarm boxes and minimize travel time.

Let  $x_j = 1$  if house  $j$  is to be filled and  $x_j = 0$  otherwise. The problem of Step 2 becomes

$$\begin{aligned} \min \quad & \sum_{j=1}^L x_j \\ \text{s.t.} \quad & \sum_{j=1}^L a_{ij} x_j \geq 1 \quad i = 1, 2, \dots, K \\ & x_j = 0, 1 \quad j = 1, 2, \dots, L \end{aligned}$$

$$\text{where } a_{ij} = \begin{cases} 1 & \text{if the } j\text{th house can cover the } i\text{th response neighborhood} \\ 0 & \text{otherwise.} \end{cases}$$

Here  $K$  is the total number of response neighborhoods and  $L$  the total number of vacant houses. This problem is the well-known "set covering problem."

The problem of Step 3 is to find available units to relocate without uncovering any of the covered response neighborhoods. The criteria adopted is to attempt to reduce, as far as possible, the mean response time during the relocation. If unit  $i$  is moved to house  $j$ , the decision-dependent "response cost" associated with this move is taken as

$$c_{ij} = (c_2 - c_1) \alpha_i (t + r_{ij}) + (c_2 - c_1) \alpha_j r_{ij}$$

$$\text{where } \alpha_\ell = \frac{\lambda_\ell \sqrt{A_\ell}}{v_\ell}$$

$\lambda_\ell$  = the alarm rate in the primary response district around station  $\ell$

$A_\ell$  = the land area of the primary response district around station  $\ell$

$v_\ell$  = the average response velocity in the primary response region around station  $\ell$

$r_{ij}$  = the time required to travel between station  $i$  and station  $j$

$t$  = the time interval over which the relocation will be in effect

and  $c_1$  and  $c_2$  are constants of proportionality associated with the response of the first and second closest units to an alarm, respectively.

This "response cost" is derived from the "square root" models of response time developed in Kolesar and Blum [A-27]. The quantity  $(c_2 - c_1) \alpha_\ell$  is an estimate of the degradation of response time in region  $\ell$  per unit time the closest company is not available. Terms in the above expression for  $c_{ij}$  thus become estimates of the decision-dependent costs at location  $i$  and  $j$  respectively, associated with a move from  $i$  to  $j$ .

Letting  $j = 1, \dots, M$  be the empty houses to be filled,  $j = M + 1, \dots, M + N$  be the available units,  $x_{ij} = 1$  if unit  $i$  is assigned to location  $j$ , and adding a "dummy" location 0 to receive all unmoved units, the problem becomes

$$\min \sum_{j=1}^M \sum_{i=M+1}^{M+N} x_{ij} c_{ij}$$



$$\begin{aligned}
\text{s.t. } \sum_{i=M+1}^{N+M} x_{ij} &= 1 & j &= 1, 2, \dots, M \\
\sum_{j=0}^M x_{ij} &= 1 & i &= M+1, M+2, \dots, M+N \\
\sum_{i=M+1}^{N+M} a_{ik} x_{i0} + \sum_{i=M+1}^{N+M} \sum_{j=1}^M a_{jk} x_{ij} &\geq 1 & k &= 1, 2, \dots, L \\
x_{ij} &= 0, 1 & \text{for all } i, j.
\end{aligned}$$

The last set of constraints requires that no response neighborhood associated with an available engine can become uncovered.

Impacts of various values of  $t$  and sequential relocations (move  $i$  to  $j$ ,  $k$  to  $i$ , etc.) on this approach are discussed. The authors conclude, however, that for  $t = 1$  hour the above formulation is adequate because preliminary analysis showed:

- (1) Relocation is usually not justified for small  $t$ .  
Relocation assignments for  $t$  much larger than 1 hour coincide with assignments for  $t = 1$ ; and
- (2) Sequential relocations do not improve the solution.  
Hence, exploring only relocations of available units to empty houses is adequate.

After Step 3, the procedure has identified  $M$  units to be relocated and  $M$  houses to be filled. The actual allocation is done in Step 4 by solving an assignment problem to minimize the time required for the relocation.

$$\min \sum_{j=1}^M \sum_{i=1}^M r_{ij} x_{ij}$$

$$\begin{aligned}
\text{s.t. } \sum_{j=1}^M x_{ij} &= 1 & i &= 1, 2, \dots, M \\
\sum_{i=1}^M x_{ij} &= 1 & j &= 1, 2, \dots, M \\
x_{ij} &= 0, 1.
\end{aligned}$$

The procedure employs heuristics for both Steps 2 and 3. The approach in Step 2 is to choose houses to occupy in decreasing order of the number of unprotected response neighborhoods covered by filling the house. The scheme used at Step 3 is to assign to house  $i$  the relocatable company  $j$  with minimum  $c_{ij}$ . The authors report that these heuristics give very good solutions.

THREATS TO  
INTERNAL  
VALIDITY:

The procedure presented makes very effective use of simplifications, approximations, and heuristics apparently appropriate for New York City. However, there is no particular reason to believe they would provide adequate models for other cities. For example, the formulations of Steps 2 and 3 would be invalid if the geography of a region required sequential repositioning.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 5.4.4, 6.3

TITLE: Fire Department Operations Analysis

AUTHOR: Labes, W. G.

REFERENCE NUMBER: A-30 and A-31

PUBLICATION SOURCES: Interim report under OCD work unit 2522F, contract N0022867C0701, IIT Research Institute, September 1966.

Final report under OCD work unit 2522F, contract N0022867C0701, IIT Research Institute, January 1968.

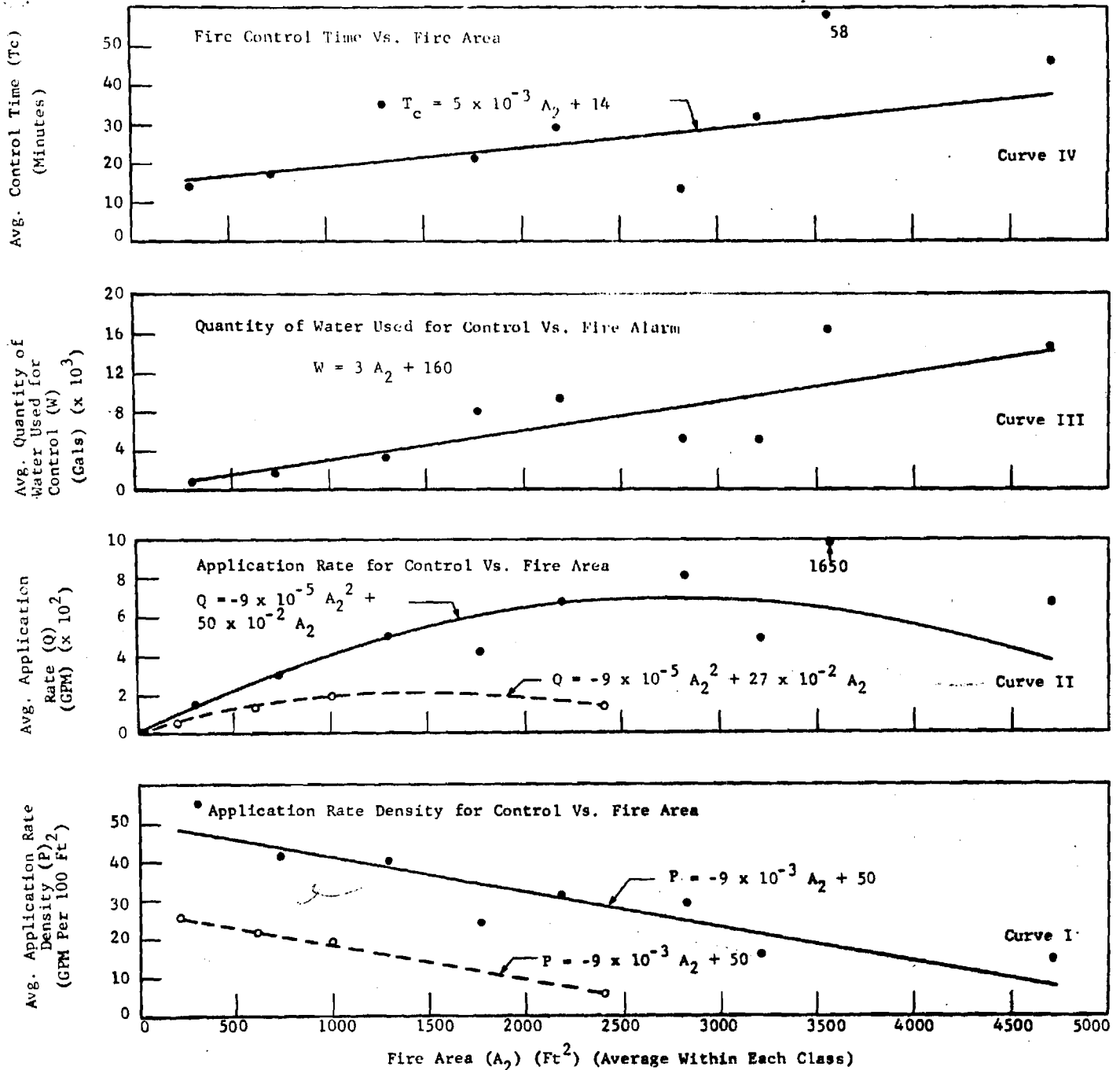
PURPOSE: To develop estimating relationships between the size of a fire and the resources required to control it in order to project the resources required to fight fires after a nuclear attack.

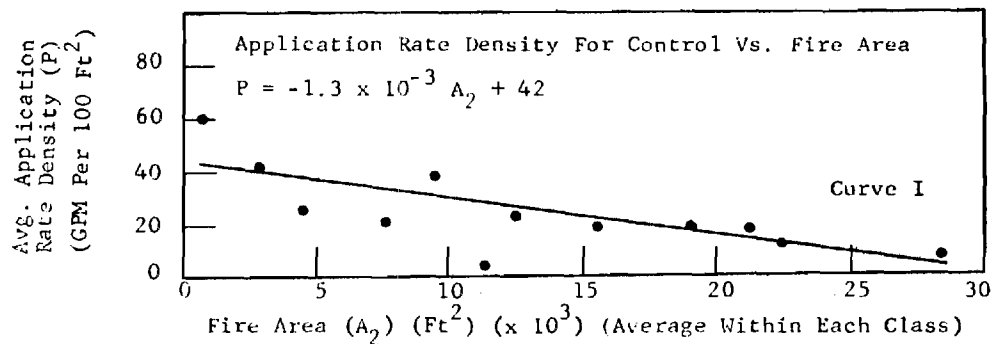
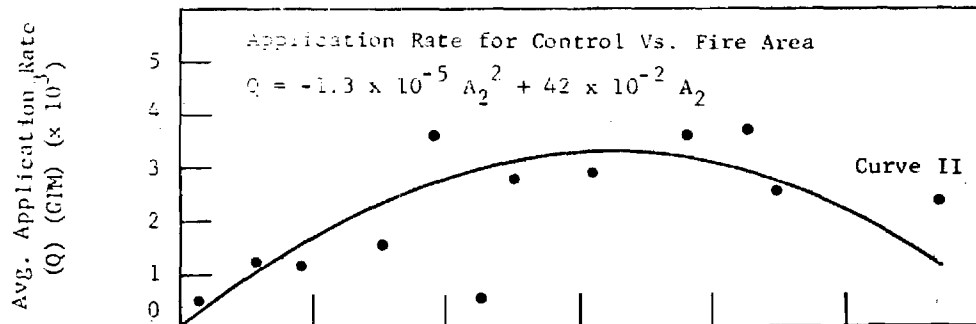
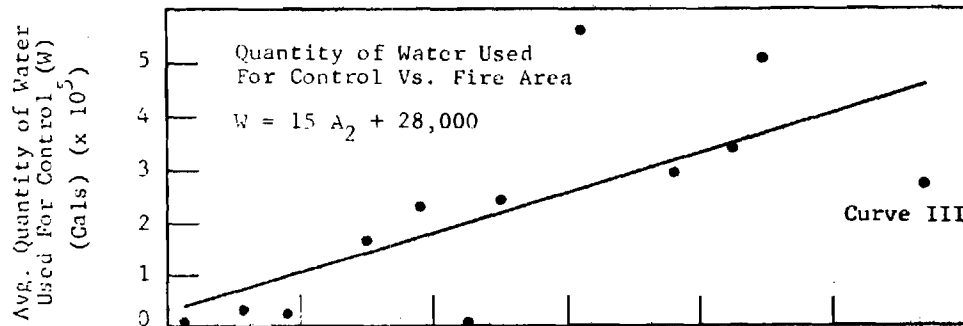
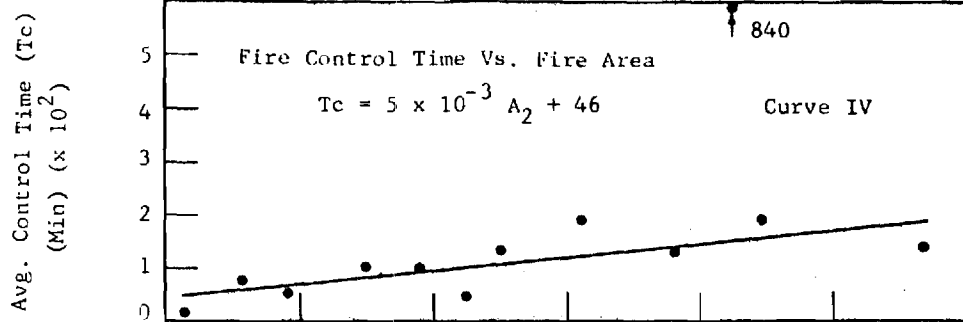
SUMMARY: Regression analysis is used to develop estimating relationships for various measures of the resources required to fight a fire as functions of the maximum area of the fire. The resulting relationships are then used to estimate fire suppression resources required after a nuclear attack.

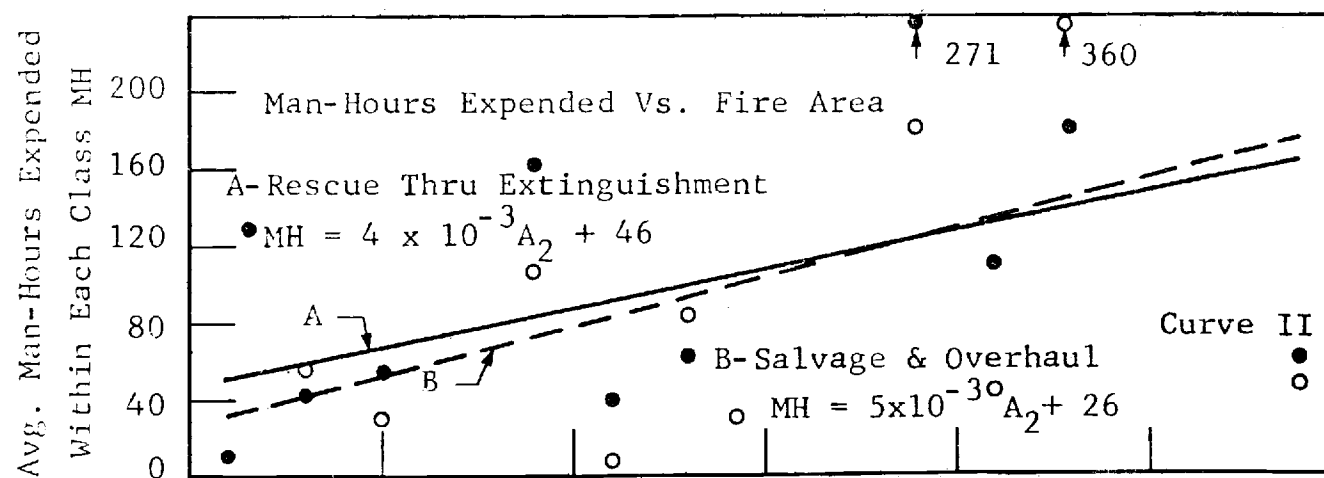
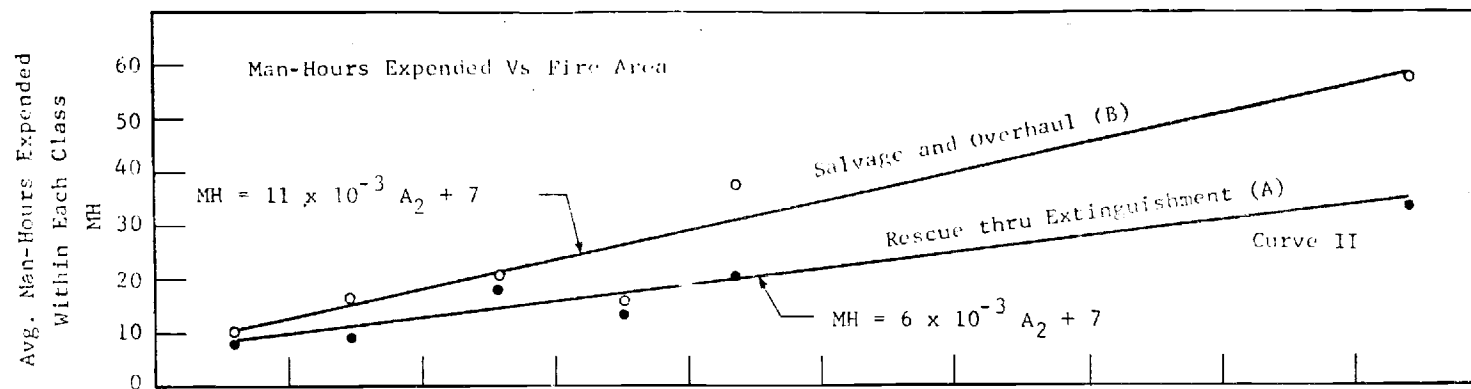
ABSTRACT: In a careful followup of 63 residential and 64 non-residential fires in the Chicago area the maximum area of each fire was determined, along with the time required to control the fire, and the arrival and departure times of all forces committed to the fire. Information on the committed forces and equipment was then used to estimate the total volume of water applied to the fires, the maximum water application rate, and the man-hours of fire-fighter's time committed to the fire.

Using this data, the author developed regression equations expressing each measure of the resources required to fight the fires as a function of the total area. These equations were, in turn, used to estimate the suppression resource requirements which would result from a nuclear attack.

For each measure of resource, and both residential and non-residential fires, the author reports development of a regression model with acceptable fit. Graphs of the regression models are shown in the following figures.







THREATS TO  
INTERNAL  
VALIDITY:

Very little information is provided about the statistical procedures used to develop the regression lines. For example, no measures of the goodness-of-fit of the models are supplied, and no description of the method for selecting the data sample is offered. Thus it is not possible to determine whether these steps in the analysis were appropriately handled.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 5.1.2

TITLE: Response of Emergency Units: The Effects of Barriers, Discrete Streets, and One-Way Streets

AUTHOR: Larson, R. C.

REFERENCE NUMBER: A-32

PUBLICATION SOURCE: Report no. R-675-HUD, NYC-Rand Institute, April 1971.

PURPOSE: To investigate the sensitivity of the mean response time of a response unit to the presence of various physical features in the served district.

SUMMARY: The sensitivity of the mean response of an emergency service unit to alarms arising uniformly over a service area is investigated. Specifically, the author calculates the change in the mean response time which results from the need to travel around barriers (e. g. rivers), and the need to travel through a discrete one or two-way street system, instead of following the direct rectilinear path. Results indicate such features do not greatly increase the expected response time.

ABSTRACT: This paper considers the sensitivity of the expected travel distance of an emergency unit located randomly in an area  $n$  blocks by  $m$  blocks to calls arising randomly and independently in the same area. If the ordinary rectilinear distance metric is used, it is well-known that the mean value of the response distance  $D$  is given by

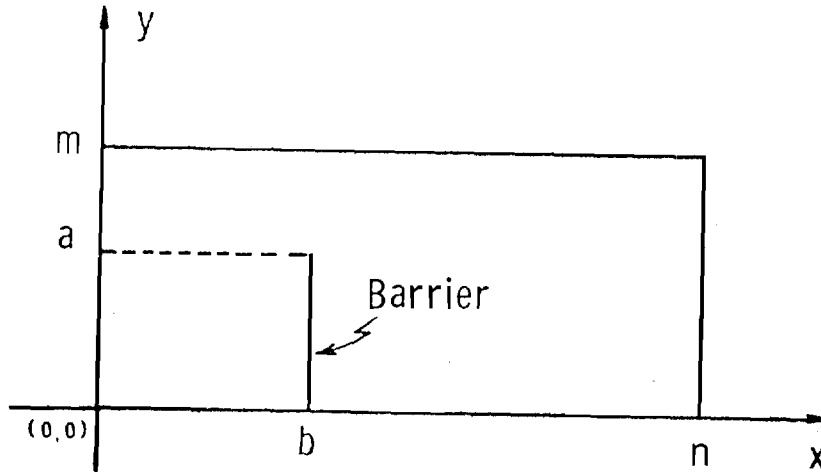
$$E[D] = (1/3) (n + m).$$

The author extends this formula to develop expressions for  $E[D']$  = the expected response distance when physical features of the response area prevent



use of the direct rectilinear path assumed in calculating  $E[D]$ .

The first such physical feature considered is a barrier, such as a river or railway, erected at  $x = b$  in the response region and extending to a height of  $a$ . Such a barrier is illustrated in the following figure.



For this case the author's calculations lead to the expression

$$E[D'] = \frac{1}{3} (n+m) + \frac{2a^2}{n^2 m^2} b(n-b) - \frac{2}{3} a.$$

In an extension where the barrier crosses the entire region, but can be crossed at point  $(b, a)$  (e. g., a river with a bridge at  $a$ ), the corresponding expression is

$$E[D'] = \frac{1}{3} (n+m) + \frac{4b(n-b)}{3n^2 m^2} (a^3 + (m-a)^3).$$

Except in extreme cases, where  $a \approx m$ , both these expressions show that the true expected response

distance is no more than 10% greater than the value  $E[D]$ .

The second class of physical features considered is a discrete, two-way street system. Instead of moving along a direct rectilinear path, units must travel along a rectangular street system, with streets arranged at unit intervals in both the  $x$  and the  $y$  directions. For this case a complex analysis yields the expression

$$E[D'] = \frac{1}{3}(n+m) + \frac{4n(m+1)m(n+1)}{3[(n+1)m+(m+1)n]^2}$$

The second term is shown to never exceed  $1/3$ , and thus the increase due to using a discrete set of two-way streets over  $E[D]$  can never exceed  $1/3$  of a block.

In a final analysis the limitation to discrete streets is extended to the case of one-way streets. The response unit is assumed to be limited to traveling over a system of one-way streets which cross the area at unit intervals and alternate in direction. For this case it is shown that the asymptotic distribution for large  $n$  and  $m$  of the number of extra blocks,  $K_e$ , which must be traversed because of the one-way streets is given by

i	0	1	2	3	4	5	6
$P\{K_e=i\}$	$1/4$	$1/4$	$1/16$	$1/4$	$1/8$	0	$1/16$

From these results,  $E[K_e] = 2$ , so that the increased travel distance caused by one-way streets in a large network will average approximately two blocks. However, a  $1/16 \approx 6\%$  minority of cases will experience

increases of as much as 6 blocks. Thus,  $E[D']$  is generally insensitive to the existence of one-way streets, but some individual responses may be significantly longer than the rectilinear metric.

THREATS TO  
INTERNAL  
VALIDITY:

None were observed.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 5.1.3

**TITLE:** On Insensitivities in Urban Redistricting and Facility Location

**AUTHORS:** Larson, R. C. and Stevenson, K. A.

**REFERENCE NUMBER:** A-33

**PUBLICATION SOURCE:** Operations Research, pp. 595-612, May-June 1972.

**PURPOSE:** To demonstrate the relative insensitivity of both minimum expected travel time to the location of emergency facilities, and optimal location of one facility with respect to location of a neighboring facility.

**SUMMARY:** The focus throughout this paper is on insensitivities in location problems. Both sensitivity of the minimum expected travel time to the relative locations of facilities, and sensitivity of the optimal location of one facility to variations in the position of a neighboring facility are considered. The analyses suggest that, in actual urban environments, detailed simulations or complex allocation algorithms relying on finely quantized data may be superfluous. Intelligent intuition may be equally valuable for planning certain aspects of such systems.

**ABSTRACT:** The paper considers problems associated with urban service systems that dispatch vehicles from fixed facilities. Specifically, it considers

- (1) Location of facilities and design of the response districts to minimize average response distance; and
- (2) Given  $N$  locations of  $N$  facilities, where should the  $(N + 1)$ th facility be located?

The study shows that when dealing with such problems, the optimal solution is unlikely to be significantly different from those obtained by heuristic methods. This is demonstrated partly by analytic means and partly by considering the case of two adjacent facilities.

Consider a square region of area  $A = 1$  with spatially homogeneous demand. The optimum location of  $N$  facilities will be at the center of  $N$  square districts, and the mean intra-district travel distance is given by

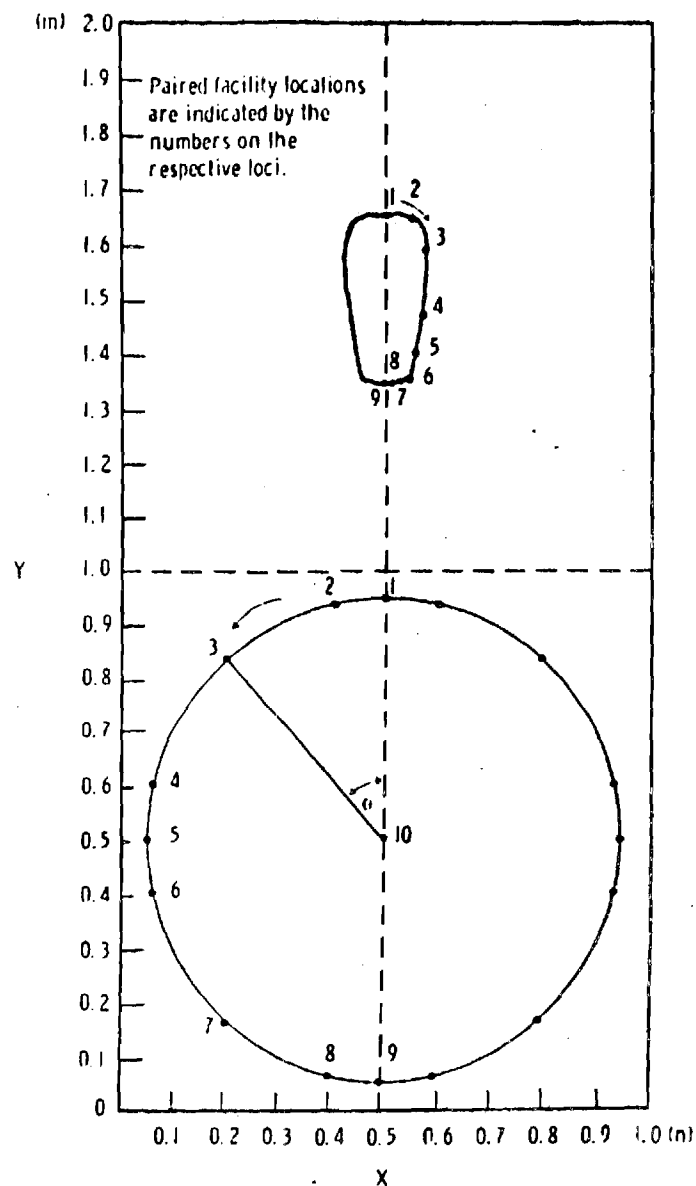
$$E^* [D] = (2/3) [2N]^{-1/2} \approx 0.471/\sqrt{N} .$$

On the other hand, if the  $N$  facilities are positioned in a totally random manner, the mean travel distance from a service request to the nearest facility is shown to be

$$E^* [D] = (1/4) \sqrt{2\pi/N} \approx 0.627/\sqrt{N} .$$

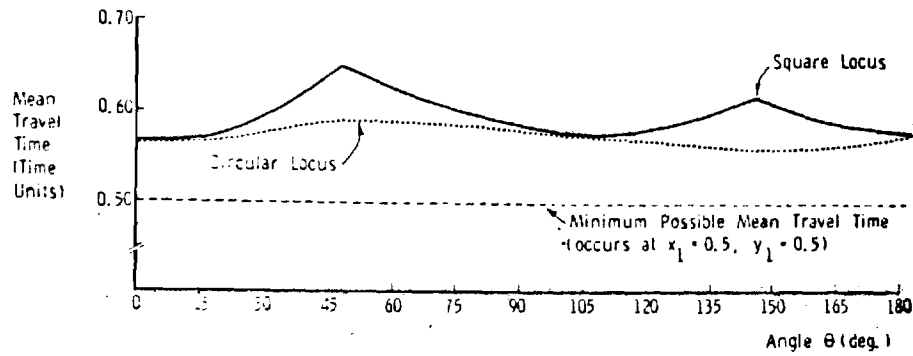
The above analysis demonstrates that the optimal positioning (and redistricting) reduces the mean travel distance by only about 25 percent over that obtained by totally random positioning.

Next the case of two facilities is considered, one having a fixed location and the other to be located optimally. The authors consider two situations. In the first, each facility serves its own response area, i.e., area to which the facility is closest. The figure below shows the optimum location of facility 2 when facility 1 is moved along a circle with center  $(0.5, 0.5)$ . Clearly, large changes in location of facility 1 result in significantly smaller changes in the location of facility 2.



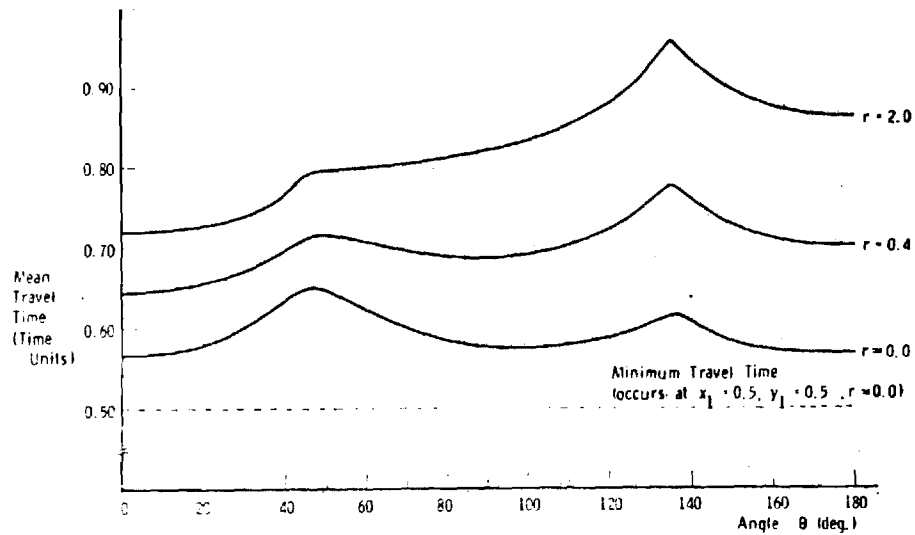
The next figure plots the expected travel time  $E(T)$  against the degree angle  $\theta$  both of this circular locus above, and also for a square locus of side length 0.9 and center (0.5, 0.5).

In the second 2-facility situation considered by the authors, each facility has a primary response region. However, if the closest unit is not free, the other unit will respond. Using a two-server, zero line-capacity queueing system model, the probabilities of



the facilities being free or busy are computed. The next figure gives the expected travel time  $E(t)$  as a function of angle  $\theta$  for the square locus in the earlier figure. It is plotted for several values of  $r = \lambda/\mu$  where  $\lambda$  is the rate of calls and  $1/\mu$  is the mean time to service each call.

As before large changes in the position of  $l$  produce only insignificant changes in the mean travel time, particularly for small  $r$ .



**THREATS TO  
INTERNAL  
VALIDITY:**

The authors acknowledge that they are working with extremely simplified models to gain insight into the sensitivity of solutions. Thus, while their analyses do provide insight, they do not by any means show conclusively that all urban facility location problems are insensitive.

**TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:**

Section 6.1.1



TITLE: The Service Facilities of the Bureau of Fire Communications: A Cost Analysis of a Proposed Consolidation

AUTHORS: Levenson, G. S. and Tenzer, A. J.

REFERENCE NUMBER: A-34

PUBLICATION SOURCE: Report no. RM-5726-NYC, Rand Corporation, September 1968.

PURPOSE: To present findings of a study dealing with the cost analysis of a proposed consolidation of engineering, installation, and maintenance facilities for the Bureau of Fire Communications, Fire Department of New York City.

SUMMARY: This report deals with a study of the cost feasibility of consolidating eleven facilities in the four boroughs of New York City. The facilities are those of engineering, installation, and maintenance of the Bureau of Fire Communications. A classic breakeven analysis was used to compare alternative plans. The study indicated that an increase in efficiency of only 6% would justify consolidation. An efficiency increase of 15% would return a savings of \$200,000 per year.

ABSTRACT: The purpose of this study was to determine potential cost benefits to be gained from consolidation of the engineering, installation, and maintenance facilities of the Bureau of Communications of the Fire Department of the City of New York. In order to perform the analysis, a functional structure of the Bureau was defined and a cost structure was devised from the conventional budget. Using this cost structure, 5-year system costs were estimated for each of six proposed consolidation possibilities.

It was not possible to perform the usual cost-benefit analysis because benefits from consolidation were mostly intangible (e. g. better supervision, more efficient use of resources, higher morale, and more efficient use of employee time). Instead, cost-benefit calculations were modeled by translating benefits into assumptions of increases in manpower efficiency (0, 5, 10, and 15 percent). That is, the previously calculated costs were reduced by these percentages for each consolidation alternative. The increase in efficiency of the consolidation alternatives were then compared to the base case (or modification of the base case) under assumptions of both growth and no growth. By this means, a point of cost indifference was determined. That is, the point at which the percent efficiency from consolidation is equal in total five-year system cost to the cost of continued use of the present facilities.

This approach resulted in the following conclusions:

- Changes in rental rate do not have a significant effect upon the attractiveness of consolidation.
- Even with no increase in efficiency, all qualitative benefits of consolidation can be obtained for a total system cost of \$150,000 per year.
- If as little as a 6 percent increase in efficiency were to be gained, the cost of consolidation would be no more than the present cost of operation
- If an increase in efficiency of 15% could be obtained, cost savings of \$200,000 per year would result.

THREATS TO  
INTERNAL  
VALIDITY:

None.

The sensitive parts of this study are the cost estimates and the method of expressing benefits. Both of these seem to be adequate.

TITLE: A Study of Telegraph - and Telephone type Fire Alarm Systems with Respect to Malicious False Alarm Incidence

AUTHOR: Lingenfelter, G. E.

REFERENCE NUMBER: A-35

PUBLICATION SOURCE: Unpublished student paper, Fire Protection Curriculum, University of Maryland, May 1966.

PURPOSE: To test the hypothesis that malicious false alarms in selected municipalities could be lessened by replacing telegraph-type alarm systems with telephone-type systems.

SUMMARY: Based upon survey responses from sixty cities of 40,000 to 500,000 population, it was concluded that the frequency of malicious false alarms is affected by the type of alarm system employed. A ratio of approximately two to one was noted in various statistics describing the occurrence of malicious false alarms for the telegraph to telephone systems respectively.

ABSTRACT: An analysis of the incidence of malicious false alarms was conducted. A questionnaire was first constructed and mailed to fire chiefs in 90 municipalities of 40,000 to 500,000 population. The questionnaire consisted of eight questions which addressed the type of alarm system and the frequency of alarms and malicious alarms observed for the calander year 1965.

Usable responses were received from 60 of the municipalities including 25 with telegraph-type, 32 with telephone-type, and 3 with both types of alarm systems. A summary of the results from these cities is given in the following table:

Number of	Fire Alarms System		Total**
	Telegraph	Telephone	
Alarms	12,658	11,642	194,215
Malicious False Alarms	8,600	3,618	17,193
Boxes	9,546	7,459	17,005
Population *	4,374,062	4,945,710	9,319,772

\* Does not include three municipalities which had both systems in service in 1965.

\*\* Discrepancies between the total figures from the sum of fire alarm system breakdowns represent alarms submitted through the public telephone system.

Five ratios were calculated from this data. For each system the number of malicious false alarms by that system was divided by (1) total number of alarms, (2) number of alarms by that system, (3) number of malicious false alarms (4) number of boxes in that system, and (5) total population of the cities with that system. For each of the five types of ratio, the telephone-type system ratio was about one-half of the telegraph-type ratio. From these ratios the author concludes that telephone alarm systems should replace telegraph alarm systems if the frequency of malicious false alarms is to be decreased.

#### THREATS TO INTERNAL VALIDITY:

A comparative survey of this type can yield insight into the likely outcome of a change in the alarm system of any given city. However, the authors broad conclusion that a reduction in malicious false alarms would result from a switch to telephone-type alarm systems cannot be fully justified unless the experience of cities making such changes has been analyzed.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 4.2

TITLE: Allocating Municipal Fire Protection Expenditures  
to Business Firms and Households According to a  
Benefits Received Criterion

AUTHOR: Malko, J. R.

REFERENCE  
NUMBER: A-36

PUBLICATION  
SOURCE: Unpublished dissertation, Purdue University, 1972.

PURPOSE: To develop and test procedures for allocating the  
cost of municipal fire protection between busines-  
ses and households on the basis of the benefit re-  
ceived by each.

SUMMARY: The allocation of municipal fire protection expend-  
itures between businesses and residences is dis-  
cussed in detail. A method of calculating the amount  
of such expenditures and two related allocation  
schemes are developed and tested in examples.

ABSTRACT: In order to estimate the amount of expenditures for  
municipal fire protection in a given year, it is  
necessary to include both operating expenditures  
and a portion of capital expenditures. The method  
proposed is to add to operating expenditures the  
portion of debt interest paid during the year which  
is allocable to fire protection and to subtract  
the net increase during the year in indebtedness  
allocable to fire prevention.

Both proposed methods for allocating fire expend-  
itures on the basis of benefits received are de-  
rived from the fire insurance rate structure. In  
the first, the standard reductions allowed by the  
American Insurance Association for different qual-  
ities of fire protection services are used to esti-  
mate the total reduction in insurance rates al-

locable to the existence of a fire department.

The method thus depends on the proportion of incremental insurance rate benefits for fire protection service enjoyed by business or residences.

The second approach seeks to allocate on the basis of total benefit received during the year. Fire expenditures are allocated in proportion to the insurance rates presently paid under the assumption that these rates closely reflect the risk of fire loss.

On the basis of rough data the first allocation scheme is applied to Milwaukee, and the second to New York City and Washington, D. C. When compared to the property tax basis in these cities, the allocating models indicate that the fractions of business and residential property in a city more closely approximate the fraction of fire protection benefits received when land values are removed from property values.

THREATS TO  
INTERNAL  
VALIDITY:

The estimation methods are preliminary and crude, but they appear to have been executed as well as possible with the available data.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 2.1.2, 2.2.4



TITLE: An Exploratory Study of Behavioral Characteristics of Certain Selected Municipal Firefighters Utilizing the Personal History Index.

AUTHOR: Marks, L. G., Jr.

REFERENCE NUMBER: A-37

PUBLICATION SOURCE: Unpublished dissertation, School of Public Administration, University of Southern California, June 1970.

PURPOSE: To identify personal characteristics which correlate with "success" as a firefighter.

SUMMARY: This study deals with identification of predictor variables on a behavioral basis that are correlated with vocational success. Information concerning personal characteristics of a selected group of firefighters was obtained by means of the "Personal History Index" (available from the University of Chicago). This information was then used to statistically examine the difference between low and high vocational success groups from the sample of firefighters. Results of the analysis indicated that a significant difference existed with respect to the following three factors:

- Early family responsibility
- Parental family adjustment
- Stability

ABSTRACT: This study is concerned with the question, "What are some predictors of vocational success which could assist in the selection of personnel?" Specifically, the research sought to identify predictor variables which could be useful indicators of vocational success in municipal fire service. After some study, the author chose to use the

judgment of the fire training officer to obtain a measure of vocational success. This was done by asking the fire training officer to rank-order the fire fighters from best to worst. The rationale was that the fire training officer was the one person who knew all the men.<sup>1</sup> The instrument used to obtain personal background information was the Personal History Index available at the University of Chicago. The Personal History Index consists of 87 items, each of which asks a question about the individual's family, education, and work experience. The scores are analyzed to obtain measures of eight performance factors, as follows:

- School Achievement
- Higher Education Achievement
- Drive
- Leadership and Group Participation
- Financial Responsibility
- Early Family Responsibility
- Parental Family Adjustment
- Stability

The Personal History Index was completed by a total of 200 fire fighters in 10 California cities. In each location, the fire fighters were ranked by their training officer and questionnaires sent to the top 10 percent and the bottom 10 percent of the rank-ordered names. The scores on the Personal History Index were then studied to determine if there was a difference between the two groups with regard to the above performance factors. Results indicated statistically significant differences between the two groups (top 10 percent and bottom 10 percent) with regard to early family responsibility, parental family adjustment, and stability.

The low vocational success group was then divided into two halves according to age. The lower age half was found to closely resemble the high vocational success group and was, therefore, utilized for a recalculation of the results. This time the three significant factors were

- Early family responsibility
- Parental family adjustment
- Total numerical index score

The change in the third factor was explained by the disproportionate number of older firefighters present in the low vocational success group.

The recommendations contained in the report are concerned with further work on the development and verification of predictor variables.

THREATS TO  
INTERNAL  
VALIDITY:

1. Ratings of vocational success made by fire training officers are not necessarily valid. They represent one opinion.
2. Validity of responses to the Personal History Index questionnaire were not verified.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 3.2.1

TITLE: Effective Planning and Allocation of Fire Prevention  
Manpower

AUTHOR: Miller, D.M.

REFERENCE NUMBER: A-38

PUBLICATION SOURCE: Unpublished dissertation, School of Industrial and Systems Engineering, Georgia Institute of Technology, November 1973.

PURPOSE: To structure some important decision problems concerning allocation and management of municipal fire prevention manpower and to develop solution procedures to analyze these problems.

SUMMARY: The specific problems addressed are (1) determination of optimum frequencies of scheduled, routine inspections, (2) determination of optimum inspection districts, and (3) determination of an optimal schedule for routine inspections. All three problems are defined and modelled. The first two are combined into a rate-district problem and solution procedure is developed and tested using data from the Atlanta Fire Department. The districts formed appear to be superior to the current set of districts with regard to work load deviation. The third problem is formulated but no solution procedure is developed.

ABSTRACT: This research deals with the general question, "How can fire prevention resources be most efficiently and effectively used?" The specific problems dealt with are (1) frequencies of scheduled, routine inspection, (2) determination of inspection districts, and (3) scheduling of routine inspections. The problems are interrelated. However, simultaneous treatment is extremely difficult because of size and complexity, and the approach in this research is to treat the first two problems together but treat the scheduling problem subsequently.

The inspection frequency problem has to do with determination of the rate of inspections in buildings of various classes. The criterion is minimization of total expected seriousness of fires. Constraints involve work load feasibility, inspection rate limits, same frequency for equivalent inspections categories (two categories are "equivalent" if the probability of realizing the same potential seriousness of fire in the two categories is the same), and integrity requirements. The districting problem involves criteria of work balance with constraints imposed by compactness and contiguity requirements. Also, each census tract must be assigned to one and only one district, and a district must be created for each inspector. In the combined rate-district problem only the expected potential seriousness is used in the objective function and the districting criteria are treated as constraints. In this approach, limits are placed on the allowable level of each of the three district problem criteria.

The objective function of the model is

$$\underset{\underline{z}, \underline{y}}{\text{Minimize}} \quad \sum_i \sum_k v_{ik} N_{ik} \sum_l p_{ikl}(z_{ik})$$

where  $z_{ik}$  = the number of scheduled, routine inspections conducted during the year in occupancy type  $k$  in census tract  $i$  ( $k=1,2,\dots,K$ ;  $i=1,2,\dots,I$ ).

$\underline{z}_i$  = the vector  $(z_{i1}, z_{i2}, \dots, z_{iK})$

$\underline{z}$  = the vector  $(\underline{z}_1, \underline{z}_2, \dots, \underline{z}_I)$

$y_{ij}$  = 1 if census tract  $i$  is assigned to district  $j$  and 0, otherwise

$N_{ik}$  = the number of  $i$ - $k$  structures

$v_{ik}$  = the potential seriousness or hazards of a fire in an  $i$ - $k$  structure

$P_{ikl}(z_{ik})$  = the probability of a type k structure  
in area i having l fires during the  
year, given an inspection rate  $z_{ik}$ .

An estimator of  $p(z)$  is obtained and is then approximated by a piece-wise linear function. The objective function and related constraints constitute a mixed-integer programming problem which, because of size, is decomposed into two sub-problems and solved by a heuristic procedure.

The criterion of expected potential seriousness requires an estimate of the effect of inspection frequency on the expected number of fires in structures of various types. A model is developed and experimental data collected to estimate the parameters. The experiment was conducted by the Atlanta Fire Prevention Bureau and experimental results were combined with subjective estimates to obtain a composite estimator.

The problem of scheduling routine inspections is discussed and a mathematical model is presented. However, no attempt is made to develop a solution method.

THREATS TO  
INTERNAL  
VALIDITY:

1. Experimental results appear to have questionable validity due to a lack of sufficient data. It is not surprising that the author found little significant influence between the effectiveness of monthly and bi-annual inspection.
2. The piece-wise approximation of the effectiveness function provides an approximation of an already somewhat "fuzzy" estimate.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 3.1, 7.2, 7.3

TITLES:           Efficient Allocation of Fire Department Resources--Part I  
                   A Model of Fire Department Resource Allocation

AUTHOR:           Mitchell, P. S.

REFERENCE  
 NUMBERS:         A-39 and A-40

PUBLICATION  
 SOURCES:         Fire Technology, vol. 7, p. 237-242, August 1971.  
                   Unpublished dissertation, University of California  
                   at Los Angeles, 1970.

PURPOSE:         To propose and test a combined heuristic and simulation  
                   procedure for improving the location of fire suppression  
                   equipment.

SUMMARY:         A set covering-type model is developed and applied to  
                   Fullerton, California which seeks to minimize  
                   either the expected travel distance or the expected  
                   response time by varying the locations of fire sup-  
                   pression equipment. Approximate optimal location  
                   plans are obtained by heuristic solution procedures  
                   and tested with an elementary simulation.

                  In developing data for the application of the model,  
                   extensive analysis of three years history in Fullerton,  
                   California is performed. Items investigated include  
                   (1) percentage of multiple response alarms, (2) dis-  
                   tribution of fire alarms over time, and (3) travel-  
                   time to distance relationships.

ABSTRACT:         The problem of locating fire suppression equipment  
                   is modeled by (1) dividing the data of interest into  
                   a set of geographically contiguous sub-regions which  
                   are assumed sufficiently homogeneous to be treated  
                   as single demand points, (2) using expected response  
                   distance or response time of the first suppression  
                   unit (or the first two if a second is required) as

a surrogate measure of fire loss, and (3) assuming the closest suppression units will always be assigned when an alarm is reported.

The resulting formulation is the set-covering problem

$$\min_{k, A_k} \sum_j p(j) \left[ \min_{i \in A_k} \{d(i, j)\} + q(j) \min_{\substack{i' \in A_k \\ i' \neq i}} \{d(i', j)\} \right]$$

where  $A_k$  = a size  $k$  subset of the potential company locations

$p(j)$  = the alarm rate at demand point  $j$

$q(j)$  = conditional probability that an alarm at  $j$  requires a second company.

$d(i, j)$  = the response time or distance from company position  $i$  to demand point  $j$ .

Extensions to deal with constraints on maximum distance of any region from a suppression unit and total capital investment are discussed but only indirectly included in the model.

The model is solved by the "ADACT" heuristic of Dielu. This procedure operates by locating units one at a time. As each new unit is located, an attempt is made to improve the solution by relocating one of the currently fixed units.

Test implementation of the procedure on data from Fullerton, California is also discussed. Several approximately optimal location plans are developed by the model and then investigated further with a simple discrete-event simulation.

Very extensive data analysis is performed in the process of the application in Fullerton. Results of



the distribution of fire alarms showed that an average of 38% of the alarms required multiple response. The same data indicated that statistically significant variations in rates of alarms are associated with the time-of-day and the month-of-the-year.

A sample of 922 responses ~~was~~ used to study the relation between response ~~time~~ and three measures of distance--response distance recorded by police, rectilinear distance between station and fire, and Euclidean distance between station and fire. Results of this analysis showed:

- Recorded response distance (mean 1.66 miles) was greater than either rectilinear distance (mean 1.31 miles) or Euclidean distance (mean 1.03 miles)
- None of the regressions yielded a highly reliable estimate of response time (correlations between observed and model times were all in the range of 0.6)
- Separation of the data into day and night groups indicated mean response is slower at night.

THREATS TO  
INTERNAL  
VALIDITY:

It appears that a superior model formulation could be developed which would more explicitly include constraints on the location plan. The approach proposed for dealing with maximum distances and budget limitations is nothing more than the idea that solutions which violate constraints will be assumed to have infinite expected responses. Evaluation of such an "infeasibility penalty" requires explicit enumeration of the solution.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 5.1.3, 5.2.1, 5.4.2, 6.1.2

TITLE: Application of Systems Analysis to the Alexandria, Virginia Fire Department

AUTHOR: Nilsson, E. K. and Swartz, J., Jr.

REFERENCE NUMBER: A-41

PUBLICATION SOURCE: Report no. 10454, U.S. National Bureau of Standards, February 1972.

PURPOSE: To demonstrate the utility of operations research approaches to problems of the fire services.

SUMMARY: This report describes how problems of fire engine availability and fire station location were analyzed in the city of Alexandria, Virginia. It includes sections on the characteristics of current fire service in Alexandria, on data collection and tabulation, on the application of queueing theory, on the application of location analysis, and on the use of simulation to analyze changes in the fire service mix in the city.

ABSTRACT: A study to demonstrate the usefulness of operations research techniques in studying fire problems in Alexandria, Virginia is reported. Data for the study were collected during May, June, July, and August, 1970. The data were taken from a company report form which is filled out by each truck and engine company responding to an alarm. It was then analyzed for distribution of calls by time of day, day of week, and type of call (public service, false alarm, and suspected and real fires), service time, and location. Statistically significant variations were observed with respect to all these factors except day of week.

Using queueing theory, the data were analyzed for resource utilization, for the probability of an alarm having to wait before being served, and the probable length of the wait. The demand distribution was assumed to be Poisson

because this distribution was tested with a Chi-Square goodness-of-fit test and could not be rejected at the 99 percent level of significance. A hypothesis was made that service times follow a negative exponential distribution, but this had to be rejected at the 99 percent confidence level. The Erlang distribution for  $k = 2, 3$ , and 4 was also tested, but had to be rejected at the 99 percent level of significance. By plotting the actual distribution of service times in the city, it was decided that the negative exponential distribution could be used to estimate an upper bound for service times. The following questions were then addressed using Markov queueing theory:

- How many companies are needed?
- What percentage of their total time is spent in answering alarms?
- What is the chance of a given number of alarms occurring per hour?
- What is the chance that there will be no equipment available for assignment when an alarm occurs?
- What is the probability of having to service a given number of alarms simultaneously?

A model developed by Chaiken [A-11] at the NYC-Rand Institute was used in these analyses to determine the probability that a given number of companies will be unavailable for service.

To analyze fire station locations, two models were applied: the Maranzana transportation model and a modification of the REDIST model, (Used to determine voting districts). The following assumptions were made to formulate the location problem as a set-cover problem:

- The important response time is that of the first engine company due, and it is that response time which should be minimized.

- Each engine company is assigned to one station at a fixed location. The company always responds from the station and is assumed to be in its station when not servicing calls.
- All alarms occurring within a zone occur at the center of that zone.
- A given fire demand zone is served by the closest engine company only.
- Travel times from each zone to each potential station location are known.

Computer simulation was used to evaluate the effect of fire station relocations produced by the set-covering procedures. The simulation model incorporated several assumptions:

- Point to point travel times could be represented by letting vehicles travel over the grid used in the previous sections of this paper. All cases occurring within a cell were assumed to originate at the center of that cell. Travel speeds were assumed to be 22.5 m.p.h. to all but public service and special calls, which were assumed to be 15 m.p.h. These speeds were viewed as reasonable by the Alexandria Fire Department for most of the area to be covered.
- Travel distance from point to point was based on the metropolitan metric, the rectilinear distance being from the (x,y) location of the fire station from which resources are dispatched to the grid coordinates of the center of the cell.
- As vehicles traveled from point to point on the grid, they traveled the entire distance in the x direction before traveling in the y direction.
- The time spent on the scene of the alarm was derived from the data as follows: For each responding company, a time of notification  $t_1$  and a time back "on

the air" (in service),  $t_2$  were available. The travel time was calculated as in the above assumptions. Using a startup time of .77 minutes, the on-scene time derived was:

$$(t_2 - t_1 - \text{total travel time} - .77)$$

Details of the data required for input to the model, and the type of information supplied as output, are included in the report.

THREATS TO  
INTERNAL  
VALIDITY:

Since the authors' objective was to demonstrate the value of approaches, rather than to actually solve problems, most of the analysis is rather superficial. However, no methodological errors are apparent from the limited information provided in the report.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 5.2.1, 6.1.2, 6.1.3, 6.4

TITLE: Is Compulsory Arbitration a Proper Tool of Public Policy? The Fire Fighters--A Case Study

AUTHOR: Oswald, R. A.

REFERENCE NUMBER: A-42

PUBLICATION SOURCE: Unpublished dissertation, Georgetown University, July 1965.

PURPOSE: To better understand the advantages and disadvantages of compulsory arbitration in settling public labor-management disputes by studying the experience of fire fighters.

SUMMARY: This study is a detailed historical investigation of compulsory arbitration as a tool for settling labor-management disputes between city governments and fire fighters. The development of both policy and experience with such compulsory arbitration is traced for Canada, the United States, and (more briefly) several other countries. Results indicate compulsory arbitration is an imperfect but viable tool of labor-management relations.

ABSTRACT: The author reports a detailed, historical survey of the policy and experience with compulsory arbitration in Canadian and U. S. fire labor disputes. The general history of compulsory arbitration policy is presented; attitudes of the International Association of Fire Fighters (IAFF) since its founding are traced; and the histories of many actual cases are discussed. The focus is on disputes between U. S. and Canadian cities and the IAFF, but some discussion of other countries is included.

The most detailed histories presented are concerned with arbitration experience in Canada. Data for this part of the paper was obtained from surveys and

correspondence with the parties involved, as well as from the arbitration documents themselves. The data is analyzed to determine the frequency of arbitration, the issues arbitrated, the procedure for arbitration, the criteria for arbitration, and the advantages and disadvantages of arbitration from both the labor and the management point of view.

The principle conclusions reached by the author can be summarized as follows:

- Experience does not substantiate the fear that the existence of a compulsory bargaining mechanism will "short circuit" the collective bargaining process. Even where such arbitration is legally available it is rarely resorted to.
- Experience indicates both labor and management will find compulsory arbitration decisions acceptable.
- Alternatives to compulsory arbitration, such as advisory arbitration, fact finding, and mediation recommendations have not been effective. Such recommendations were merely ignored by the stronger party in the dispute.
- The primary criteria used in compulsory arbitration decisions have been compared to "related" occupations, and changes in the cost-of-living.
- Statistical data suggest fire fighters' wages are not significantly affected by the lack of or availability of compulsory arbitration.

THREATS TO  
INTERNAL  
VALIDITY:

Since this study involves a great deal of descriptive case-history information and very little quantitative data, the conclusions reached are necessarily the



subjective judgments of the author. Other persons might reach other conclusions, and more widespread use of compulsory arbitration would not necessarily result in the outcomes suggested by the author.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 3.2.3

TITLE: Determining How Many Companies to Dispatch Using Mathematics

AUTHOR: Ottoson, J.

REFERENCE NUMBER: A-43

PUBLICATION SOURCE: Fire Chief, pp. 43-46, January 1973

PURPOSE: To provide an approximate technique for determining the appropriate number of fire suppression units to send to various types of alarms.

SUMMARY: An elementary probabilistic model is presented for empirically evaluating plans for the number of fire suppression units to send to a given type of alarm on the basis of the risk that the number of units dispatched will not be adequate. Under some strong assumptions, the technique provides a basis for comparing existing responses to different sorts of alarms and for proposing changes in the planned responses.

ABSTRACT: The probability that the fire response will be inadequate for a given fire; i.e., the probability that reinforcements are required,  $P(RR)$ , can be empirically estimated for a given type of fire call as

$$P(RR) = \frac{\left( \begin{array}{c} \text{Number of calls requiring} \\ \text{reinforcements} \end{array} \right)}{\left( \begin{array}{c} \text{Total number} \\ \text{of calls} \end{array} \right)}$$

In this paper the author proposes using the statistic  $P(RR)$  as a measure of the effectiveness of the plan for response to various types of calls. If this probability is significantly above or below an acceptable overall risk level in the case of some type of alarm, he suggests the planned response to that alarm type should be changed until  $P(RR)$  agrees with the planned risk.

In order to determine a revised number  $K$ , of units to dispatch to any type of alarm, the author suggests

estimating the cumulative distribution function  $F(N)$  of the number of units,  $N$ , ultimately required at an alarm of the given type.  $K$  is then chosen using this estimate,  $\hat{F}(N)$ , so that

the acceptable level of  $P(RR) = 1 - \hat{F}(K)$  .

$\hat{F}(N)$  is estimated by simply tabulating the proportion of a sample of the given alarm type which ultimately required  $N$  or fewer suppression units.

THREATS TO  
INTERNAL  
VALIDITY:

The author implicitly makes some strong assumptions, including that

- The response to each fire is determined without consideration of ongoing fires or the need to be prepared for new fires;
- The risk of requiring reinforcements should be equal across all alarm types; and
- The number of suppression units required by a fire is unaffected by the sequence in which they are dispatched.

However, no attempt is made to explicitly state the assumptions. Thus, while technically not incorrect, the paper could be misleading.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 6.2.1

TITLE: Optimal Quantity of Fire Department Services

AUTHOR: Pickett, J. C.

REFERENCE NUMBER: A-44

PUBLICATION SOURCE: Unpublished dissertation, University of Missouri-Columbia, 1970.

PURPOSE: To examine, in an economic framework, the economics aspects of fire protection including cost, demand, and supply functions. A major objective is to obtain greater insight into the cost-benefits structure of fire department service so that the consumer (community) is in a position to ascertain so-called optimal levels of service quantity.

SUMMARY: This study is concerned with the determination of an "optimal" quantity of fire protection service. The work involves the following major elements:

- Analysis and measurement of fire department output
- Development of a cost function for forecasting fire department total costs
- Market analysis and development of a method for measuring marginal benefits and marginal costs

The study concludes that an appropriate criteria for decision making is to produce that quantity of fire department services for which marginal benefits (savings in insurance premiums) equal marginal costs.

ABSTRACT: Demand by property owners for fire protection is translated into a demand for fire department services and fire insurance. Pickett's work is an effort to develop a means to determine the point at which incremental costs of fire protection are equal to incremental benefits arising from insurance premiums reductions.

Annual data for the years 1950-1965 were obtained from 14 cities in Missouri and a linear cost model was developed. Regression equations were obtained for each of the cities and cross-sectional equations were obtained for each year.

The report proposes that fire protection professionals consider the insurance grading and determine the total deficiency points necessary to raise the communities insurance rating by one classification. Each combination of feasible corrective measures for achieving the necessary reduction of deficiency points is costed and the minimum cost alternative is selected. This, according to the study, provides the marginal cost of increasing measured output one unit. Marginal benefits to the community are to be measured by the reduction in the price of fire insurance. The optimal quantity of fire protection service is defined as the point at which marginal benefits equal marginal costs.

THREATS TO  
INTERNAL  
VALIDITY:

1. Variables included in the cost model are strongly interrelated "quantity" factors.
2. The grading number is affected by many factors outside the control of the fire department and is not a good measure of fire department output.
3. Costs of fire protection service are not distributed in the same way as the fire insurance premium reductions which result from a improved insurance classification. Thus the criterion for optimality may produce cost inequities.

TEXT COM-  
MENT ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 2.1.1, 2.1.2, 2.2.2, 2.2.3

TITLE: A Principal Components Analysis of the Determinants of Local Government Fiscal Patterns

AUTHOR: Pidot, G. B., Jr.

REFERENCE NUMBER: A-45

PUBLICATION SOURCE: The Review of Economics and Statistics, vol. 51, no.2, p. 176-188, May 1969.

PURPOSE: To investigate statistically the reduction between social-economic indicators and revenue/expenditure patterns in major metropolitan areas.

SUMMARY: The effects of thirty social-economic variables on 1962 local government fiscal patterns is investigated via principal components analysis. Results indicate that "metropolitanism", "general wealth" and "size" had substantial effects on per capita expenditures and revenues.

ABSTRACT: The author investigates the effect of a number of social and economic measures on 1962 fiscal patterns in 81 major metropolitan areas. The original independent variables are the following:

$V_1$  =1963 retail sales per capita.

$V_2$  =1963 wholesale sales per capita.

$V_3$  =1963 selected service receipts per capita.

$V_4$  =1963 value-added in manufacturing per capita.

$V_5$  =Per cent of 1960 housing built since 1950.

$V_6$  =Per cent of 1960 housing in sound condition.

$V_7$  =Per cent of 1960 housing units with more than 1.0 persons per room.

$V_8$  =Per cent of 1960 housing units renter occupied.

- $V_9$  =Average annual net migration rate from 1950 to 1960.
- $V_{10}$  =Per cent 1960 population nonwhite.
- $V_{11}$  =Per cent 1960 population 65 years old and over.
- $V_{12}$  =Per cent 1960 employed population using public transportation to work.
- $V_{13}$  =Per cent 1960 work force in Standard Metropolitan Statistical Area (SMSA) core living outside.
- $V_{14}$  =Per cent 1960 labor force in agriculture.
- $V_{15}$  =Per cent 1960 families owning one or more cars.
- $V_{16}$  =1960 income per capita (Census definition).
- $V_{17}$  =Per cent 1960 families with annual incomes under \$3,000.
- $V_{18}$  =1961 per capita value of taxable property at market value.
- $V_{19}$  =Per cent of 1961 taxable property other than commercial and industrial.
- $V_{20}$  =Average annual population growth rate from 1950 to 1960, in logs.
- $V_{21}$  =1962 core area population, in logs.
- $V_{22}$  =1962 population density, in logs.
- $V_{23}$  =1962 average population per independent non-school government unit, in logs.
- $V_{24}$  =1962 average enrollment per school system, in logs.
- $V_{25}$  =1961-62 public school enrollment per cent of population.
- $V_{26}$  =1962 per cent of entire SMSA population living in core area.

The author uses principal components techniques to reduce these variables to a set of uncorrelated composite variables. The six such variables produced are intuitively interpreted as a measure of the metropolitanism of the city, a measure of the general wealth in the city, a measure of the size of the city, a measure of the degree of old age and poverty in the city, a measure of the degree of commercial development in the city, and a measure of the relative stagnation of the city.

The author next performs a regression analysis of per capita revenues and expenditures, using these composite variables and measures of the amount of state and federal financial aid as independent variables.

Regression equations are developed for per capita expenditures for a number of municipal services, per capita revenues for various taxes and charges, and per capita indebtedness of several types.

Results of this analysis showed metropolitanism, general wealth and size had widespread and significant effects on expenditures and shifted the pattern of revenues. State and federal aid also appeared to have stimulative effects on expenditures.

THREATS TO  
INTERNAL  
VALIDITY:

None were observed.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 2.2.3



TITLE: Public Fire Protection: Costs, Demands, and Pricing

AUTHOR: Pollak, W.

REFERENCE NUMBER: A-46

PUBLICATION SOURCE: Unpublished dissertation, Princeton University, 1973.

PURPOSE: To investigate and analyze fundamental issues in fire protection service as follows:

- Meaning and measurement of fire protection output
- Fire protection cost function
- Fire protection demands
- Issues in the provision of fire protection service

SUMMARY: This study consists of deductive analyses of several fundamental issues in fire protection. Included is the meaning and measurement of output, costs, demands, and methods for changing costs to the users of fire protection services. General models are provided and some empirical evidence is given which supports conjectural claims.

ABSTRACT: This study is concerned with several important issues in fire protection service. Fire protection service output is subjectively examined from the standpoint of both quantity and quality. The examination concludes that output measurement must pertain to physical quality rather than value and to what is provided to beneficiaries rather than the product of producer-beneficiary interaction. Accordingly, the output measure recommended is "suppression capability".

The author next proceeds to develop an analysis of factors which influence fire protection service costs. Based upon this analysis, a cost function of the following form is suggested:

$$\text{Total Cost} = KA^{\alpha} N^{\beta} f(\hat{d})$$

In this function A denotes area, N denotes population,  $\hat{d}$  denotes service level,  $\alpha$  is close to but less than one and  $\beta$  is close to but greater than zero.

Following the development of the above cost model, the author examined several empirical cost studies. It was argued that these studies were faulty because they fail to include a service level variable or include a defective one.

Factors affecting the demand for fire protection service were discussed but no quantitative analysis is attempted. The discussions serve as input to subsequent discussions of issues in the provision of fire protection service. In these discussions, primary attention is given to the feasibility of implementing fees to finance fire suppression service. Other issues discussed are: (1) alternative ways of organizing the fire protection service, and (2) optimum protection service levels.

THREATS TO  
INTERNAL  
VALIDITY:

The deductive analyses are logical, interesting and stimulating. However, there is no way to evaluate internal validity.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 2.2.1, 2.2.3, 2.5

TITLE: An Evaluation of the Placement of Fire Stations in a City; A Case Study

AUTHOR: Raouf, A.

REFERENCE NUMBER: A-47

PUBLICATION SOURCE: Paper presented at the 41st National Meeting, Operations Research Society of America, April 1972.

PURPOSE: To develop a method for periodic assessment of fire station locations based upon the distance of a fire from the firehouse and the size of the fire.

SUMMARY: A method is developed for rough, periodic review of the positions of fire stations within fixed, response districts. The method relies on estimates of response distance weighted by the resources required to suppress fires. Application in Windsor, Canada is discussed.

ABSTRACT: The author proposes an approximate method for periodic evaluation of the locations of N fire stations, each located in a different district with predetermined boundaries. The measure of effectiveness proposed for the location of the nth station is the weighted response distance

$$K_n = \sum_i D_{i_n} M_{i_n}$$

where  $D_{i_n}$  is the actual distance of the ith fire in the nth district from the current firehouse location and  $M_{i_n}$  is the corresponding man-hours spent extinguishing this fire. For a given period, the optimal locations  $(\hat{x}_n, \hat{y}_n)$  are suggested to be the centroids

$$\hat{x}_n = \frac{\sum_i M_{i_n} x_{i_n}}{\sum_i M_{i_n}}$$

$$\hat{y}_n = \frac{\sum_i M_{i_n} y_{i_n}}{\sum_i M_{i_n}}$$

where  $(x_{i_n}, y_{i_n})$  are the Cartesian coordinates of the ith fire in district n.

The optimal value of the measure of effectiveness,  $K_n^0$ , is determined by estimating what response distance would have been from  $(\hat{x}_n, \hat{y}_n)$  and substituting in the above expression for  $K_n$ .

For a city of N districts the corresponding overall measure of effectiveness is

$$K_N = \sum_{n=1}^N \sum_i D_{i_n} M_{i_n}$$

If  $K_N^0$  is calculated in the same way the percent increase in effectiveness due to having the N stations located optimally is approximated by

$$E = \left[ \frac{K_N - K_N^0}{K_N} \right] \times 100.$$

This formulation is applied to fire data of Windsor, Ontario. For the six fire stations in Windsor, values of  $K_n$  for existing fire house locations and  $K_n^0$  for optimal location of the n district firehouses are calculated. It is suggested that  $K_n$  be evaluated for each station every year, since the trend in  $K_n$  versus time may suggest the need of relocation.

THREATS TO  
INTERNAL  
VALIDITY:

1. The author's statements of notation are conflicting as to the choice of a distance metric for estimating  $K_n^0$ .
2. The paper implicitly makes numerous assumptions and simplifications in development of the proposed approach. While these assumptions are loosely motivated on grounds of the need for a "quick and dirty" method, they are never explicitly stated. Thus the overall effect of the paper is misleading.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 5.2.2.1, 6.2.1

TITLE: Input, Performance and Demand Measures for Fire-Fighting Services

AUTHOR: Rider, K. L.

REFERENCE NUMBER: A-48

PUBLICATION SOURCE: Report no. WN-8180-NYC, NYC-Rand Institute, June 1973.

PURPOSE: To develop and investigate the implications of various measures of the fire-fighting service provided different regions of a city.

SUMMARY: A number of alternative measures of the fire protection service provided different regions of a city are proposed and investigated. Measures include the allocable expenditures per land area, allocable expenditures per capita, and hazard-weighted response time. Details of estimating these measures in New York City are presented, and the implications of the results for equity of service are discussed.

ABSTRACT: The author develops and estimates from New York City data a number of measures of the fire-fighting service provided different regions of the city. Under the assumption that expenditures for fire protection are roughly approximated by fire department expenditures, the first part of the paper undertakes an extensive analysis of New York City Fire Department expenditures. Using standard cost accounting techniques, the expenditures are allocated among 21 hazard regions.

The expenditure allocation produced from this analysis is then used to develop two measures of the service provided each region. The allocable expenditure per square mile, and the allocable expenditure per capita are calculated for each region.

A second portion of the study investigates simple analytic measures of response time to each of the regions. In particular, response performance is normalized under the assumption that current fire company allocation is optimal with respect to the optimization model

$$\begin{aligned} \min \quad & \sum_i \lambda_i (\tau_i - u)^{\frac{1}{p}} h_i^{\frac{1}{p}} \\ \text{s.t.} \quad & \sum_i n_i = M \end{aligned}$$

where  $\tau_i$  = the mean response time in region  $i$   
is approximated by

$$\alpha_1 (n_i - b_i)^\beta A_i^{-\beta}$$

$n_i$  = the number of units assigned to region  $i$

$b_i$  = the expected number of busy units in  
region  $i$

$A_i$  = the land area of region  $i$

$\lambda_i$  = the alarm rate in region  $i$

$M$  = the total number of units available

and all other factors are empirically determined parameters. The degree to which current allocations are optimal for this model is offered as a measure of the degree of "rationality" in the allocation.

The author shows that the optimal response time for this model,  $\tau_i^*$ , will be approximately of the form

$$\tau_i^* = \gamma_1 \rho_i^{-\delta} + \gamma_0$$

where  $\rho_i = \lambda_i/A_i$ . Regression analysis demonstrates that more than 90% of the variance of the  $\tau_i$  can be

explained by this simple model, when  $\tau_i$  are derived independently from the "square root" model of Kolesar [A-26]. Thus, while the response time service provided various parts of the city is quite different, a large part of that variation can be explained on the basis of the "rational" consideration of the variations in  $\rho_i$ .

THREATS TO  
INTERNAL  
VALIDITY:

The "square root" formula used in the regression analysis is quite similar in form to the model based on  $\rho_i$ . Thus the close agreement between the formulas could be expected, and that agreement cannot be taken as convincing evidence that the  $\rho_i$  expression does explain the variation between regions.



TITLE: A Parametric Model for the Allocation of Fire Companies: Formulation, Solution and Interpretation

AUTHOR: Rider, K. L.

REFERENCE NUMBER: A-49

PUBLICATION SOURCE: Report no. WN-8551-HUD/NYC, NYC-Rand Institute, March 1974.

PURPOSE: To propose and test a simple model for allocating fire companies among a set of regions on the basis of minimizing an estimate of response time derived from simple parameters of the sub-regions.

SUMMARY: A simple parametric model for allocating fire companies among regions of a protection district is investigated. The model form is briefly motivated; a closed-form, Lagrange multiplier expression for the optimal solution is derived; and test application of the model in New York City is discussed.

ABSTRACT: The author formulates and tests a simple, parametric model for allocating M companies among a set of regions of a protection district. Drawing on the earlier "square root" work of Kolesar and Blum [A-27], Kolesar and Walker [A-28], and Kolesar [A-26], the mean response time to region i given  $n_i$  units are assigned,  $\tau(n_i)$ , is estimated by

$$\tau(n_i) = \alpha_4 \left[ \frac{A_i}{n_i - b_i} \right]^{\frac{\alpha_2}{2}} + u$$

where  $A_i$  = the land area of region i  
 $b_i$  = the mean number of companies busy in region i

$u$  = the turnout time for fire companies  
and the  $\alpha$ 's are empirical constants derived through regression.

The proposed form of the allocation problem then becomes

$$\begin{aligned} &\text{minimize} \quad \sum_i w_i (\tau_i (n_i) - u)^\beta \\ &\text{subject to} \quad \sum_i n_i = M \end{aligned}$$

where the  $w_i$  are weights which reflect the importance of response performance in the various regions, and  $\beta$  is a tradeoff parameter controlling the balance of response performance across the district. When  $\beta = 1$ , the formulation minimizes district-wide response time; as  $\beta$  becomes larger, exceptionally long response times in some regions are discouraged.

To develop the "hazard weights,"  $w_i$ , the author considers two types of demand. The existing, realized demand is measured by  $\bar{\lambda}_i$  = the mean number of companies working in region  $i$  per unit time. Potential hazards are included through a "hazard factor"  $h_i$ . The resulting expression is  $w_i = \bar{\lambda}_i h_i^\beta$ . This definition of weights is shown to have the added advantage that  $\beta = 0$  is now the case of equalizing company workloads.

In this final form a closed-form, analytic solution to the model is developed via Lagrange multipliers. The solution is

$$n_i^* = \bar{\lambda}_i^{-v} h_i^{v\beta} A_i^{(1-v)} N + b_i$$

$$\text{where } N = \left[ \begin{array}{c} \sum_1 \frac{v}{\lambda_1} h_1^{\beta} A_1^{(1-v)} \end{array} \right] \left[ \begin{array}{c} M - \sum_1 b_1 \end{array} \right]$$

$$\text{and } v = \frac{2}{\alpha_2 \beta + 2} .$$

Test application of the model in New York City is also discussed. For this purpose the city was divided into 16 relatively homogeneous residential hazard regions. Results calculated from the model are given in the following table.

	Current Policy	Optimal for $\beta=0$	Optimal for $\beta=1$	Optimal for $\beta=3$	Optimal for $\beta=\infty$
Mean Response Time (mins)	3.40	3.36	3.35	3.38	3.68
Minimum Regional Mean Time (mins)	2.79	2.55	2.69	2.90	3.68
Maximum Regional Mean Time (mins)	4.33	5.46	4.91	4.42	3.68

Clearly, variations in coverage among regions can be reduced with relatively small changes in overall mean response.

THREATS TO  
INTERNAL  
VALIDITY:

None were observed.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 5.2.2.1, 5.4.4, 6.1.1

TITLE: A Computer Model for Evaluating Fire Station Location  
Location of Fire Stations

AUTHORS: Santone, L. C. and Berlin, G. N.

REFERENCE NUMBERS: A-51 and A-52

PUBLICATION SOURCES: Report No. 10093, U. S. National Bureau of Standards, August 1969.

Systems Analysis for Social Problems, edited by Blumstein, A., Kamrass, M., and Weiss, A. B., Washington Operations Research Council, 1970.

PURPOSE: To describe models for evaluating fire stations locations developed in a study of East Lansing, Michigan.

SUMMARY: In locating a new fire station, the impact of its location on current needs and future needs should be considered. Explicitly ranking alternative locations would be more justified than attempting to find "optimal" locations. The two papers discuss general strategies for ranking locations that were developed in East Lansing, Michigan. The ranking is done by combining information on response time and frequency of fire with subjective measures of the importance of adequate coverage.

ABSTRACT: A city can be described by a network of links (roads) and nodes (intersections of roads). If an index listing of all the structures exists, and the structures are associated with nodes so that a fire in a structure can be assumed to occur at the associated node, the effectiveness of a fire station location  $i$  can then be represented by

$$W_i = \sum_j T_{ij} D_j.$$

Here  $T_{ij}$  is the travel time from location  $i$  to each of the nodes,  $j$ , "covered" by location  $i$ , and  $D_j$  is the "demand" of protection from  $j$ . The location  $i$  with the lowest  $W_i$  value is the most preferred location.

The models discussed in these papers are detailed implementations of such evaluation schemes conceived as part of a study of East Lansing, Michigan. In each case the travel times  $T_{ij}$  are determined as the shortest time-path through a computer representation of the city street network. For East Lansing, the time on each link was determined by dividing the length of the link by the posted speed.

A number of different approaches to calculating  $D_j$  are discussed. All consider  $D_j$  in the form defined by

$$D_j = \sum_k D'_j(k)$$

Where  $D'_j(k)$  is the fire protection demands for the  $k$ th structure associated with node  $j$ . The structure demand  $D'_j(k)$ , in turn, is expressed by

$$D'_j(k) = P_{j(k)} L_{j(k)}$$

where  $P_{j(k)}$  is the probability of a fire at structure  $k$  of node  $j$ , and  $L_{j(k)}$  is the value of the loss due to a fire. The  $P_{j(k)}$  can be approximated from experience, and thus the problem in calculating  $W_i$  is resolved to calculating the  $L_{j(k)}$ .

The first scheme suggested for determining  $L_{j(k)}$  was to estimate the risk at each individual structure from historical data by regression on characteristics of the structure

(number of residents, floor space area, etc.). However, this procedure was not pursued because sufficient data was not available.

The second approach attempted was to derive subjective measures of the risk at various types of structures (schools, hospitals, single-family dwellings, etc.) on the basis of rankings by members of the city staff and research analysts assigned to the project. This approach was also rejected because sufficient uniformity could not be obtained in the rankings proposed by the various participants.

A third approach involved an effort to make the subjective evaluations more systematic. Regression was performed to express the average subjective risk assigned in the previous analysis in terms of the characteristics of typical structures of each type. The characteristics considered included the number of persons endangered, the number of floors in each building, construction type, area of the structure, and area of each floor.

The approach ultimately adopted closely parallels this statistical approach. In lieu of the weights derived through regression, subjective weights were developed for each of the above characteristics of buildings. These weights were then applied to typical specifications for various types of structure. Thus the measure of demand ultimately proposed by the authors involves a structure-by-structure analysis of risk, with the risk at each structure being developed by subjectively weighing a number of relevant characteristics of the building. The authors report that this approach produced results acceptable to city officials in East Lansing in spite of its informality.

THREATS TO  
INTERNAL  
VALIDITY:

The authors repeatedly use comparison to historical loss patterns as a method for validating the demand estimators. Since that loss is affected by the current locations of

fire stations, there is no particular reason an objective measure of risk should correspond to the historical pattern.

TEXT COMMENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 5.1.3, 5.2.2.1, 6.1.2



TITLE: The Allocation of Resources in Municipal Fire Protection

AUTHOR: Stacey, G. S.

REFERENCE  
NUMBER: A-53

PUBLICATION  
SOURCE: Unpublished Ph.D. dissertation, Ohio State University,  
1973.

PURPOSE: To develop models for the allocation of fire companies  
to various areas of a given fire jurisdiction.

SUMMARY: A linear programming formulation is developed for the  
problem of allocating a fixed number of fire companies  
to a set of points in a fire jurisdiction in a way which  
maximizes one of several measures of the protection pro-  
vided. Details of application of the model in Dayton,  
Ohio are also provided.

ABSTRACT: In this paper the author considers models for allocating  
fire companies with respect to several different measures  
of "protection." With all such measures, it is assumed  
that the protection provided  $n$  areas by  $d$  units at  $m$  sta-  
tions can be expressed as

$$p = \sum_{i=1}^n \sum_{j=1}^m p_{ij} x_j$$

where  $x_j$  = the number of the  $d$  units at station  $j$  and  
 $p_{ij}$  = the protection provided area  $i$  by each unit  
at station  $j$ .

The corresponding "optimal" allocation is then derived  
from the linear program

$$\begin{array}{ll} \min & p \\ \text{s.t.} & \sum_{j=1}^m x_j \leq d \\ & \sum_{j=1}^m p_{ij} x_j \geq C_i \quad i = 1, 2, \dots, n \end{array}$$

$$b_j^1 \leq x_j \leq b_j^2$$

where  $C_i$  is a minimum level of protection to be provided area  $i$ , and  $b_j^1$  and  $b_j^2$  are the minimum and maximum numbers of companies which can be assigned to station  $j$ .

Four different measures of  $p_{ij}$  are discussed. All assume  $p_{ij}$  is inversely proportional to the distance  $d_{ij}$  from station  $j$  to area  $i$ . Specifically, the measures are a population based measure

$$p_{ij}^r = \tilde{r}_i / d_{ij}$$

where  $\tilde{r}_i$  is the fraction of the jurisdiction's resident and commuter population located in area  $i$ ; a property-value based measure

$$p_{ij}^v = \tilde{v}_i / d_{ij}$$

where  $\tilde{v}_i$  is an estimate of the fraction of the jurisdiction's property loss experienced by area  $i$ ; an aggregate measure

$$p_{ij}^a = (\tilde{v}_i + \alpha_i \tilde{r}_i) / d_{ij}$$

where  $\alpha_i$  is a weighting factor for area  $i$ ; and a measure derived from the existing allocation

$$p_{ij}^e = \bar{x}_j / d_{ij}$$

where  $\bar{x}_j$  = the existing number of units at station  $j$ .

For each of these measures a set of  $C_i$  are determined as a "normalization factor"  $\theta$  times the corresponding protection coefficient for area  $i$ , i.e.,  $\theta \tilde{r}_i$ ,  $\theta \tilde{v}_i$ ,

$$\theta(\tilde{v}_i + \alpha_i \tilde{r}_i) \quad ,$$

and

$$\theta (\sum_j \bar{x}_j / d_{1j}) / (\sum_i \sum_j \bar{x}_j / d_{1j}) .$$

The factor  $\theta$  is necessary because all protection measures are dimensionless, and thus the  $C_i$  are difficult to determine directly. However, since no other basis is available for selecting  $\theta$ , the author repeatedly solves the linear programs corresponding to given measures of protection until the largest values of  $\theta$  yielding feasible solutions are determined. The  $x_j$  which produce these "maximum  $\theta$ " feasible solutions are then deemed optimal.

Extensive discussion is also provided in the paper of the application of these models in Dayton, Ohio. All data elements of the four models were estimated from actual Dayton experience, except that  $\alpha$  was fixed at 1. Results showed coefficients of correlation with the existing allocations of .421, .300, .212, .614 for the aggregate, property, population, and existing measures of protection respectively. Thus, the measures produced allocations which were different from each other and from the allocation now employed.

#### THREATS TO INTERNAL VALIDITY:

The development in this paper consists almost entirely of piling unvalidated and sometimes unstated assumptions on top of other unvalidated and sometimes unstated assumptions. Thus while the work is mathematically sound, additional analysis would be required before the proposed model could be recommended as a tool for fire suppression resource allocation. For example, more motivation and support would be necessary for the scheme of choosing  $\theta$  by reducing the stated optimization problem to finding a feasible solution with  $\theta$  as large as possible.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 5.2.2.1, 5.4.2, 5.4.4, 6.1.2

TITLE: A Mathematical Formulation of the Fire Engine Relocation Problem

AUTHOR: Swersey, A. J.

REFERENCE NUMBER: A-54

PUBLICATION SOURCE: Report No. D-18682-NYC, NYC-RAND Institute, June 1969.

PURPOSE: To propose a mathematical programming formulation of the problem of relocating fire companies when certain areas of the protected jurisdiction become inadequately covered because units regularly assigned in the areas are busy at fires.

SUMMARY: A mixed-integer, warehouse-location-type model of the fire company relocation problem is proposed. The formulation seeks to minimize the total "cost" of relocation, including both a fixed cost of moving companies and the expected "cost" of the response pattern which will result from the relocation.

ABSTRACT: The author addresses the problem of relocating the  $m$  available fire companies at the  $M$  possible locations in order to improve the pattern of response to incidents at  $k$  demand points. He assumes there is a fixed cost  $C$  associated with any company movement, and that the expected "cost" of an incident at demand point  $i$  is a function of the  $b$  closest occupied company locations. For each such location  $j$ , this cost is given by

$$\alpha_{ij} = p_i \sum_{s=1}^n p_{is} f(i,s,d_{ij})$$

where  $p_i$  is the probability of an incident at point  $i$ ,  $p_{is}$  is the conditional probability that an incident at  $i$  is of type  $s$ , and  $f(i,s,d_{ij})$  is a function depending on the location  $i$ , the type of incident  $s$ , and the distance  $d_{ij}$  from

i to j. Under these assumptions, the author formulates the problem in the mixed-integer warehouse-location form

$$\min \sum_{j=1}^M \sum_{i=1}^k \alpha_{ij} x_{ij} + \sum_{j=1}^M C(1-O_j) y_j$$

$$\text{s.t. } \sum_{j=1}^M x_{ij} = b \quad i=1, \dots, k$$

$$\sum_{i=1}^k x_{ij} \leq k y_j \quad j=1, \dots, M$$

$$\sum_{j=1}^M y_j = m$$

$$y_j = 0, 1 \quad j=1, \dots, M$$

$$0 \leq x_{ij} \leq 1 \quad i=1, \dots, k; j=1, \dots, M$$

$$\text{where } y_j = \begin{cases} 1 & \text{if company location } j \text{ is to be occupied} \\ & \text{after the relocation} \\ 0 & \text{otherwise} \end{cases}$$

$$x_{ij} = \begin{cases} 1 & \text{if location } j \text{ is to be one of the } b \text{ closest} \\ & \text{occupied locations to demand point } i \text{ after the} \\ & \text{relocation} \\ 0 & \text{otherwise} \end{cases}$$

$$O_j = \begin{cases} 1 & \text{if company location } j \text{ is occupied before the} \\ & \text{relocation} \\ 0 & \text{otherwise} \end{cases}$$

A solution will indicate (from the optimal  $y_j$  values) which  $m$  of the  $M$  locations should be occupied. To determine the actual company moves required, it is suggested that an assignment problem be solved. Such a problem would find the minimum travel distance of each company  $k \in \{k: O_k=1, \text{ the optimal value of } y_k=0\}$  to a location  $j \in \{j: O_j=0, \text{ the optimal value of } y_j=1\}$ .

THREATS TO  
INTERNAL  
VALIDITY:

1. The separation of the problem into a part which chooses stations to be manned and a part which selects the movement assignment can introduce sub-optimality. A more complete (though complex) approach would include the costs of actual movements in the objective function of the first problem.
2. There is no apparent reason why the assignment phase of the formulation should not permit the movement of companies in presently occupied locations which will be occupied after the relocation. Such an extension would allow sequential, "accordian" relocations if they were appropriate.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 6.3

TITLES: Models for Reducing Fire Engine Response Times  
Reducing Fire Engine Dispatching Delays

AUTHOR: Swersey, A. J.

REFERENCE A-55 and A-56  
NUMBERS:

PUBLICATION Unpublished dissertation, School of Engineering and  
SOURCES: Applied Sciences, Columbia University, 1972.  
Report no. R-1458-NYC, NYC-Rand Institute, December 1973.

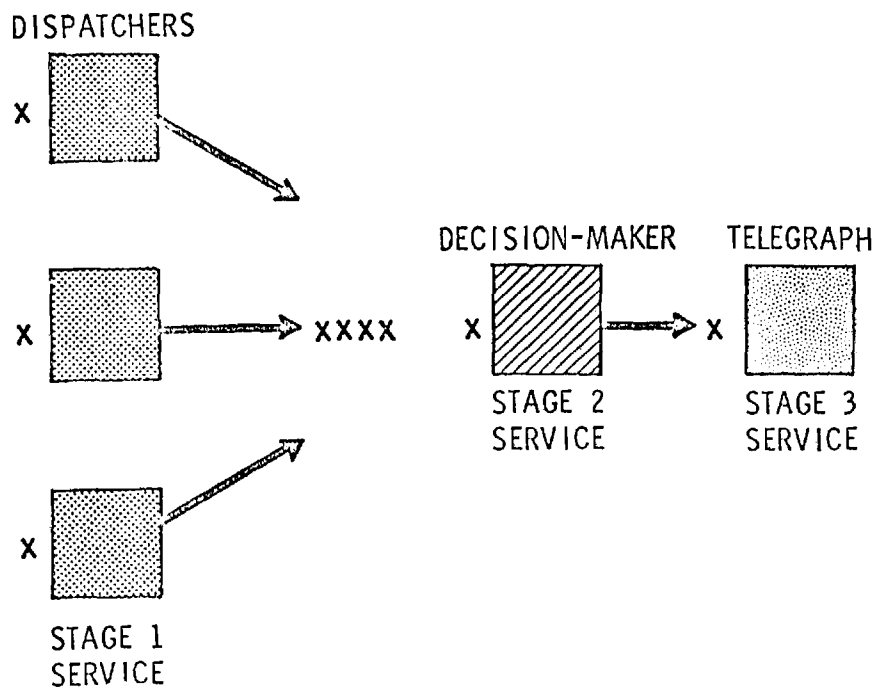
PURPOSE: To develop mathematical models which can be used to  
analyze and reduce delays in fire suppression dispatch  
operations.

SUMMARY: Two related problems in the planning of dispatch  
efforts for fire suppression forces are addressed.  
A first part of the analysis deals with the evaluation  
of the workload capacity of a particular dispatch  
facility. The facility is modeled as a two-stage  
queueing system, and simulation is used to estimate  
the delay experienced by incoming calls as a function  
of the alarm rate.  
  
A second phase of the dissertation then deals with  
models for automating the decision processes of dis-  
patchers so that the delay can be reduced. A semi-  
Markov model of the question "How many units should  
be dispatched to an alarm?" is developed, and several  
different solution procedures presented.

ABSTRACT: The author analyzes the delays experienced by incoming  
calls at a fire dispatch office, and automated pro-  
cedures for reducing these delays. Since dispatch  
delay is a significant component of the time between  
the filing of an alarm and the arrival of fire companies  
(i. e., response time), the analysis can also be  
interpreted as an effort to reduce response time.



The initial phase of the research is an empirical analysis of the dispatch environment using data from the Brooklyn Communications Office of the New York City Fire Department. The dispatch process is modeled as a three-stage queueing system like the one in the figure below.



Stage 1 of this process includes all activities of an individual dispatcher in recognizing an alarm and selecting the appropriate "response card" with a recommended response. Stage 2 is the decision-making effort of the dispatch supervisor. A senior Fire Department officer must make decisions on the proper response to each alarm. Stage 3 includes the time to transmit the decision after it has been taken. Since this stage was found to be relatively unimportant in the total time through the system, it was disregarded in the remainder of the analysis.

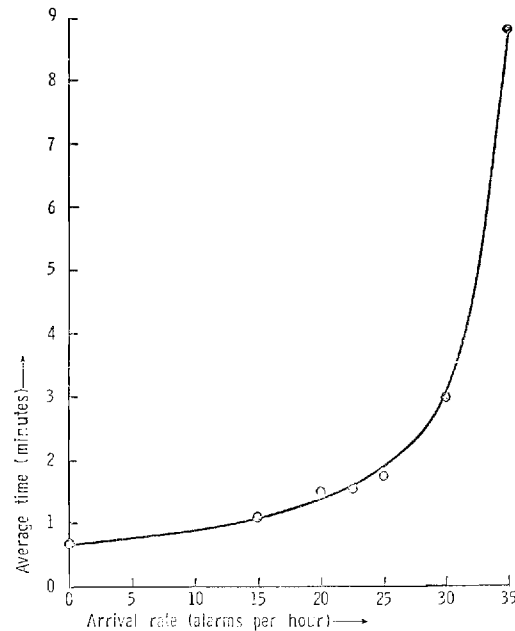
The author's primary interest is in Stage 2. A queueing model is developed which sub-divides that stage into two phases, and data were collected on the distribution of times in Stage 1 and each phase of the Stage 2. Chi-square goodness-of-fit tests are used at each step to fit the distributions, with all except one being either exponential or a constant plus exponential.

Results of these empirical steps are collected in a simulation model of the dispatch process. The model is briefly validated, and then used to estimate the average dispatching time as a function of the incoming alarm rate. The curve derived by this process is presented in the figure on the following page

The results of the simulation analysis demonstrated that the total dispatch time could be substantial when the alarm rate is high, and that the principle delay is in the decision-making of stage 2. Thus the author turned to mathematical models which might be used to automate some elements of the dispatch decision process.

Specifically, the problem of "How many units should be sent?" is considered. The problem is modeled as a semi-Markov decision process where the states of the

system are associated with the number of units busy.



For simplicity, the author provides detail only on the decision of "Should the dispatcher send one unit or send two units?" This decision is viewed as one which should hinge on the relationship between the probability that an alarm signals a "serious" alarm (i. e., one requiring two companies) and a criterion or "cutoff" value. The cutoff value is calculated to reflect the response time tradeoff between sending one unit when two are needed and thus delaying the response of the second unit; versus sending two units when one is needed, and increasing overall response time by unnecessarily occupying a unit. If the probability that an alarm is serious is above the criterion value, the decision rule sends two.

A linear programming formulation of the problem is presented which provides an exact solution to the problem of determining the criterion value for various system states and response time weighting functions. However, this model proves too bulky for implementation in an on-line decision process. Thus, two approximate solution schemes are developed and shown to produce good results.

THREATS TO  
INTERNAL  
VALIDITY

There appear to be some methodological difficulties with the statistical procedures used at various stages of the simulation part of the study. The author demonstrates the exponential nature of the random variables of interest, but uses procedures based on the Normal distribution to fit regression lines to the data. Similarly, if more careful statistical procedures had been used in the comparisons of simulated and actual data, it is not clear that the same conclusions about the growth of dispatch delay with alarm rate would have been reached.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 4.3, 5.2.1, 6.2.1.

TITLE: A Systematic Analysis of San Diego County's Fire System: A Special Reference to the Status of Local Government in the United States

AUTHOR: Thompson, L.

REFERENCE NUMBER: A-57

PUBLICATION SOURCE: Unpublished dissertation, University of Southern California, 1973.

PURPOSE: To make a systematic study of San Diego County's fire protection needs and alternatives available to meet them, and to recommend a method of meeting the needs.

SUMMARY: This study took an inventory of San Diego County's fire resources, analyzed how these resources were being used, and recommended a strategy of change that would improve the overall efficiency of the county's fire protection system.

ABSTRACT: The data for this study was collected through a questionnaire (mostly open-ended) followed by an interview. An analysis of the responses and the recommendations may be summarized as follows:

- Geographic boundaries: Structural fire protection is predominantly in the western half of the county covering about 1/4 of the area (neglecting military installations). Slightly 50% of the county is under the control of public agencies. The remaining 1/4 of the county formed islands with partial protection. The future trends pointed towards rapid growth. The recommendation was to adopt minimum standards for fire protection in unincorporated areas.

- Facilities, Equipment and Personnel: Questionnaires revealed that a number of fire districts had planned on expansion mainly in new stations. The recommendations were that the county develop a long-range development plan with more formal training in cooperative facilities (as recommended for insurance grading) and also academic training in fire sciences in colleges.
- Fire Prevention: There was not general enthusiasm about effecting fire prevention methods. It was recommended that a uniform fire code be adopted with full-time personnel, trained in inspection, undertaking the inspection program.
- Financing: There was a general negative reaction from the public for tax increases even though they expect adequate service. The author recommends that the county explore the possibility of low-cost financing to ease the immediate burden. Centralized buying should be adopted to affect reduction in expenditures.
- Mutual Aid: Gray areas appeared to exist in the command structure at the various alarm states. It was recommended that the county Fire Chief's Association establish a review committee and extend the radio system to give total coverage.

While the above recommendations were based on responses to the questionnaire, there were other potential avenues of action open to the county to improve the operation of the fire services. They included annexation, metropolitan federation, functional

consolidation, and city-county consolidation. It was felt that the most expedient avenues of problem solution lay in area consolidation through metropolitan federation or functional consolidation. Metropolitan federation refers to the consolidation of fire service only (as opposed to total integration in annexation). Functional consolidation involved the consolidation of only one particular function.

The advantages of such an area consolidation were many fold and are discussed in detail in the thesis. However, consolidation should be undertaken after a study of its impact on current fire structure; e. g., legal provisions, role of district boards, retirement plans to be merged, affect on salary benefits and job security.

THREATS TO  
INTERNAL  
VALIDITY:

1. The selection of variables to investigate is based more on intuition than on the open systems theory point of view.
2. The conclusions and recommendations are basically subjective.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 3.

TITLES: A Determination of the Optimum Location of Fire-Fighting Units in New York City

A Statistical Determination of the Distribution and Number of Engine and Ladder Companies in the City of New York

AUTHOR: Valinsky, D.

REFERENCE NUMBERS: A-58 and A-59

PUBLICATION SOURCES: Operations Research, vol. 3, p. 494-512, November 1955.

Mayor's Committee on Management on Management Survey, City of New York, 1952.

PURPOSE: To develop and execute a quantitative method for locating the fire suppression companies of the New York City Fire Department.

SUMMARY: This paper describes a New York City study of fire company location. An initial set of locations is derived from requirements of the National Board of Fire Underwriters. These locations are then improved on the basis of regression-derived hazard measures calculated for each part of the city, and a review of experience on several very busy nights for the Fire Department.

ABSTRACT: This study considers the "optimum" location of fire-fighting units in New York City to cope with fires under normal operation and under extraordinary circumstances.

The locations are obtained in four phases. First, an initial set of locations are determined using the maximum response distance recommendations of The National Board of Fire Underwriters. Locations in this set either meet or exceed all distance criterion.



Next, a model for prediction of fire incidence is developed which is used to study continued availability of services and performance under extreme circumstances. This information is used to modify the locations.

To obtain a model for prediction, land use classifications were first combined into eight groups, each constituting a fire hazard. Based on statistics from a period of five years, a fire hazard index for each group was obtained by

$$F_i = \frac{\text{Area (in } 10^5 \text{ sq. ft.) of group } i}{\text{Average number of fires per year}} \quad i = 1, 2, \dots, 8.$$

For a given tract with land use under different groups the fire hazard potential was then obtained as

$$\sum_{i=1}^8 (A_i / F_i)$$

where  $A_i$  is the group  $i$  area in the tract under consideration.

Using this measure of fire-hazard potential, a socio-economic index derived as the ration of population density to average rental together with the number of commercial and manufacturing establishments in an area, a regression model was used to predict fire incidence. The model is

$$\log Y = \log a + x_2 \log b_2 + x_3 \log b_3 + x_4 \log b_4$$

where  $Y$  = fire incidence

$x_2$  = fire-hazard potential

$x_3$  = socio-economic index

$x_4$  = number of commercial/manufacturing establishments in an area.

An auxiliary measure of fire demand is also developed. This measure is a "fire-proneness index" defined for each type of building occupancy by

$$\left[ \begin{array}{c} \text{Fire-proneness} \\ \text{index} \end{array} \right] = \frac{(\text{Average no. of fires in building in a class})}{(\text{Total no. of buildings in the class})}$$

This index reflects the different risks associated with different building occupancies.

The author reports adjustment of the original locations on the basis of both these indices. The third and fourth phases of the study were then used to further refine the locations. In the third phase a detail study of the company workload pattern implied by the locations was performed; and in the fourth phase the locations were tested for there adequacy during two recent, and very busy, nights for the Fire Department.

THREATS TO  
INTERNAL  
VALIDITY:

The author provides no details of his movements of company locations, but it is clear that no formal optimization procedure was used. Thus the locations derived would be "optimum," as the title states, only in a very subjective sense.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 5.2.1, 5.2.2.1, 6.1

TITLE: The Dimensions of Juvenile Arson and False Alarm for the Urban Areas of San Diego

AUTHORS: Vernon, R. F. and Bigger, W. R.

REFERENCE NUMBER: A-60

PUBLICATION SOURCE: Report of the Urban Observatory of San Diego, San Diego, California, November 1972.

PURPOSE: To explore the problems and backgrounds involved in juvenile arson and false fire alarms.

SUMMARY: Juvenile arson and false fire alarms are studied using data from San Diego, California. The data are tabulated by characteristics of persons involved and by characteristics of the fires and false alarms.

ABSTRACT: Two hundred cases from a file of 713 cases of juvenile arson and false alarms in the urban areas of San Diego were analyzed by frequency tabulations. For the problems of both false alarms and fires as a whole, two age groups, seven and thirteen year olds, were most often involved. Females were seen to be involved in 10% of the fire related offenses. From frequency plots on maps, juvenile arson was seen to cross socioeconomic and ethnic lines--affecting many altogether different communities.

Locations of the fires tended to be in schools or adjacent grounds. Apprehension by school officials accounted for over 40% of those caught. Temporarally the largest occurrences of juvenile arson were seen to be at the beginning and end of the school year with the largest percent of incidents occurring in the morning hours before school and secondary peak during the noon hour. Categories of fire and non-fire offenses were tabulated as well as means employed in the setting of fires as indicated in the following table.

# CATEGORIES FOR FIRE AND NON-FIRE OFFENSES

	Percent	N-200 Frequency
Fire Offenses:		
Fire in or on a building/plant (other than simple play)	63.0%	126
Grass/Brush Fires	14.5	29
Playing with matches (simple)	5.0	10
Fire Works Detonation	3.5	7
Fire to a Person	2.5	5
Personal Property	2.0	4
Sub Total	90.5%	181
Non-Fire Offenses:		
Sales or Gifts of Firecrackers	3.5%	7
False Alarm, Unknown Location	2.5	5
False Alarm in School	2.0	4
False Alarm Near School	1.5	3
Sub Total	9.5%	19
Unknown/Not Apply	0.0%	0
Total	100.0%	200

# MEANS OF SETTING THE FIRE

	Percent	Frequency
Simple Matches or Lighter	45.8%	82
Fireworks	26.2	47
Trash Cans	18.5	33
Bomb or Incendiary Device	5.0	9
Flammable Liquids	4.5	8
Total	100.0%	N=179

Tabulation of the student characteristics were also made. The mean grade point average was 1.88/4.00, however, 17% of those children involved were in classes for exceptional children. A little over one third of the children involved showed attendance problems in school. Six out of ten children involved had some preceived problem

in their social adjustment. These statistics are summarized in the table below.

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SOCIAL ADJUSTMENT

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	Percent	Frequency
No comment	40%	20
"Acts out"	24	12
Has a temper	14	7
Bully	10	5
Immature/Attention seeker	6	3
"Runt"	4	2
Braggart	2	1
Total	100%	50

---

A family structure analysis was also comiled. The results are shown in the following table.

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FAMILY STRUCTURE

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	Percent	Frequency
Living with mother and father	61.5%	123
Living with mother only	23.0	46
Living with father only	7.5	15
Living with father and step-mother	6.5	13
Living with mother and step-father	0.5	1
Living with other relatives	0.5	1
Other situations	0.5	1
Total	100.0%	200

---

THREATS TO  
INTERNAL  
VALIDITY:

Any inferences or insights contained in the tabulated data for only those apprehended in juvenile arson and false fire alarms, such as the characteristics of the juveniles who became involved should be compared with similar information concerning those who do not become involved.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 7.1, 7.3

TITLE: Approaches to the Solution of the Fire Engine Relocation Problem

AUTHORS: Walker, W. E. and Shinnar, S.

REFERENCE NUMBER: A-61

PUBLICATION SOURCE: Report no. D-19519-NYC, NYC-Rand Institute, November 1969.

PURPOSE: To propose and test alternative algorithms for solution of the fire company relocation problem as formulated by Swersey in [A-54].

SUMMARY: Alternative solution procedures for the formulation of the fire company relocation problem presented in Swersey [A-54] are investigated. A heuristic and an exact method for solving the first, mixed-integer portion of that formulation; and two different procedures for the second, assignment portion of the formulation are discussed and compared.

ABSTRACT: In [A-54] Swersey proposed a mathematical programming formulation for the problem of relocating  $m$  available companies among the  $M$  company positions when some parts of a fire jurisdiction are inadequately covered as a result of all nearby units being busy at fires. For a set of  $k$  demand points, each of which can gain some level of service from the  $b$  closest companies, the first, mixed-integer portion of this formulation is

$$\begin{aligned}
 \min \quad & \sum_{j=1}^M \sum_{i=1}^k \alpha_{ij} x_{ij} + \sum_{j=1}^M c(1 - \delta_j) y_j \\
 \text{s.t.} \quad & \sum_{j=1}^M x_{ij} = b \quad i = 1, 2, \dots, k \\
 & \sum_{i=1}^k x_{ij} = ky_j \quad j = 1, 2, \dots, M
 \end{aligned}$$

$$\sum_{j=1}^M y_j = m$$

$$y_j = 0, 1 \quad j = 1, \dots, M$$

$$0 \leq x_{ij} \leq 1 \quad i = 1, \dots, k; j = 1, \dots, M$$

$$\text{where } y_j = \begin{cases} 1 & \text{if company location } j \text{ is to be occupied} \\ & \text{after the relocation} \\ 0 & \text{otherwise} \end{cases}$$

$$x_{ij} = \begin{cases} 1 & \text{if location } j \text{ is to be one of the } b \text{ closest} \\ & \text{occupied locations to demand point } i \text{ after} \\ & \text{the relocation} \\ 0 & \text{otherwise} \end{cases}$$

$$\delta_j = \begin{cases} 1 & \text{if company location } j \text{ is occupied before} \\ & \text{the relocation} \\ 0 & \text{otherwise} \end{cases}$$

$C$  = a fixed cost of any company movement

$\alpha_{ij}$  = an expected response cost of having location  $j$  be one of those covering demand point  $i$

$b$  = the number of companies near a demand point which can provide any coverage.

The solution of the above problem yields a set of  $m$  locations to be occupied after the relocation, i.e.,  $m$  locations with optimal value  $y_j^* = 1$ . An assignment problem is then solved to decide how to move companies at locations with  $\delta_j = 1, y_j^* = 0$  to locations with  $\delta_j = 0, y_j^* = 1$ . The objective function of the assignment problem is to minimize travel distance in accomplishing the relocation.

In this paper the authors propose and test two algorithms for each of these two phases of Swersey's formulation. The first procedure for the mixed-integer phase is an exact, implicit enumeration approach. The essence of the



procedure is to initialize the  $y_j$  at 1, i.e., assume all locations are occupied, and search for a subset of  $(M-m)$   $y_j$ 's to fix at 0. The next  $y_j$  in sequence is always the one chosen to be newly fixed at value 0, and backtracking occurs when the cost of the current partial solution plus the sum of the incremental costs of independently forcing an additional  $r$  of the  $y_j$ 's to 0 exceeds the cost of a known feasible solution. Here  $r$  is  $(M-m) - (\text{the number of } y_j \text{ fixed at 0 in the present partial solution})$ .

The second algorithm considered by the authors for the mixed-integer portion of the problem is a simple heuristic. Passing once through the  $(M-m)$  locations with  $\delta_j = 0$ , the procedure determines whether a move from any presently occupied location could reduce total cost. If such a move is possible, then the one which most reduces cost is effected, and the procedure continues.

The two procedures were computationally compared using  $M = 36$ ,  $\alpha_{ij}$  and  $b$  derived from experience with Rand's computer simulation of the New York City Fire Department, and various values of  $m$ ,  $k$ , and  $C$ . Results indicated that the exact procedure required several minutes to solve all non-trivial problems, and in some cases had not reached optimality after 15 minutes of calculation. The heuristic provided optimal solutions in almost every case, and typically consumed less than one minute.

Two different procedures for the assignment phase of the algorithm were also investigated. One is the Balinski-Gomory procedure which is "dual to" the Hungarian method. A second is a branch-and-bound scheme derived from the exact algorithm given above. The results of tests with these procedures proved the Balinski-Gomory technique clearly superior.

THREATS TO  
INTERNAL  
VALIDITY:

The development of the presented algorithms appears to be correct, but many other approaches are available in the operations research literature for dealing with problems similar to those presented by Swersey.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 6.3

TITLE:           Scalar Economies and Urban Service Requirements: A  
Method for Determining the Economies of Scale Associated  
with Municipal Governmental Services, When Offered at  
Required, Standard Levels, with an Empirical Application  
to Fire Protection Services

AUTHOR:           Will, R. E.

REFERENCE  
NUMBER:           A-62

PUBLICATION  
SOURCE:           Unpublished dissertation, Yale University, September 1964.

PURPOSE:           To develop a methodology for relating the cost of urban  
services to city size.

SUMMARY:           This study develops an approach to measuring total urban  
service needs in terms of "standard units of effort."  
By costing these for cities of various sizes, scalar  
economies (or diseconomies) can be studied. Fire pro-  
tection services are studied as an empirical part of the  
investigation.

ABSTRACT:           Every municipality provides certain common services such  
as police protection, sanitation, fire protection, etc.  
These services are usually measured and analyzed in terms  
of actual expenditures. This study is an attempt to find  
the required amount of any given service and to determine  
the "units" of resources required. The relationship  
between total work and city size (population) yields in-  
formation on economies of scale.

The use of actual expenditures can be misleading since  
they depend on diverse factors and need not be a measure  
of either service provided or needed. If  $n_i$  is the  
service need for service  $i$ , ( $i = 1, 2, \dots$ ), then it is  
assumed that

$$n_i = \sum_j w_{ij} x_j$$

when  $x_j$  is the incidence (value) of indicator  $j$  and  $w_{ij}$  is the amount of need for service  $i$  arising from indicator  $j$ . The indicators may be different types of services (when dealing with police protection) or different types of fires (when dealing with fire protection). The indicators are selected such that adequate data are available or can be collected. The values of  $w_{ij}$  can usually be specified by professionals; e.g., an authority on protection can specify the time required by a policeman to attend a specific type of crime. When this is not possible, average capability can be found through analysis of data.

The service need is met by consuming resources. Let  $a_{ik}$  be the amount of the  $i^{\text{th}}$  service need met by one  $k^{\text{th}}$  standard unit of effort (S.U.E.), i.e., consumption of one standard unit of resource. If service need and S.U.E. are measured in comparable terms (e.g. service need in total man-hours and S.U.E. in number of men), the amount of the  $k^{\text{th}}$  resource needed to meet service  $i$  can be obtained by dividing the  $i^{\text{th}}$  service need by  $a_{ik}$ . Thus, service need can be converted readily into resource need.

The cost of all the services needed is

$$c = \sum_{i,k} c_k \left( \frac{n_i}{a_{ik}} \right)$$

Here  $c_k$  is the uniform price for one unit of the  $k^{\text{th}}$  S.U.E. This is usually taken as the median of input prices actually paid in a number of cities ranging in size as well as in other characteristics. By studying the values of  $c$  for various cities, scalar economies can be investigated.

The proposed procedure is applied to 38 cities in order to study scalar economies in fire protection. For reasons

of practicability in data requirements, the "ideal" method described above is abandoned and an approximation is used to obtain cost estimates. Using the ISO Standard Schedule, estimates are made of S. U. E.'s required to achieve the same level of protection in each of the 38 cities. These S. U. E.'s are converted to costs per capita which are intended to show the costs of reaching a uniform level of protection in cities of various sizes. The costs are related to population by regression analysis and it is concluded that there are significant economies of scale up to a population of 300,000 and very little from that point on.

THREATS TO  
INTERNAL  
VALIDITY:

1. As recognized by Will, the scalar economies that were measured in the study were inherent, at least to some degree, in the use of the insurance grading schedule.
2. The standards used do not reflect the possibility of large cities suffering from political difficulties not found in medium size cities.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 2.2, 3.1

TITLE: Aspects of Organization Structure and Organizational Efficiency: A Study of Municipal Fire Departments

AUTHOR: Yahr, H. T.

REFERENCE NUMBER: A-63

PUBLICATION SOURCE: Unpublished dissertation, New York University, June 1965.

PURPOSE: To examine the relationships, if any, between several aspects of the structure of an organization and the effectiveness of the organization.

SUMMARY: This study is concerned with the relationships between variables of organizational structure in municipal fire protection services and organizational effectiveness. A sample of 32 fire departments was used and eleven test hypotheses are constructed and evaluated.

ABSTRACT: The purpose of this study was to investigate the effect of several variables of organizational structure on the efficiency of the organization. These variables were:

- Size--the number of full-time, paid personnel
- Departmentalization--the number of major organizational units
- Levels of authority--the number of designated levels in the formal authority structure
- Administrative component--the proportion of organizational personnel formally engaged in administrative activities

The matter of "centralization" of administrative activities within a city was not included as a study variable but it was taken into account in the selection of the sample. The effectiveness score used in the

study was the fire department subscore based on the insurance grading schedule.

The sample consisted of 32 fire departments located in municipalities with populations of 25,000 or more. Data were obtained from each fire department and statistical methods were used to test eleven hypotheses. Following is a summary of the findings:

- The administrative component is unrelated to organizational size and departmentalization.
- The administrative component is positively correlated with levels of authority.
- Departmentalization is positively related to levels of authority.
- Organizational size is not related to levels of authority.
- Organizational size is positively related to area specialization.
- Organization size is not related to organizational efficiency.
- Departmentalization is positively related to organizational efficiency.
- Levels of authority is not negatively correlated with organizational efficiency.
- There is no relationship between the administrative component and organizational efficiency.

**THREATS TO  
INTERNAL  
VALIDITY:**

The fire department subscore of the insurance grading schedule is a questionable measurement of organizational effectiveness.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Section 3.1



TITLE: Application of Systems Management Techniques to  
Fire Protection Operations

REFERENCE  
NUMBER: A-64

PUBLICATION  
SOURCE: Final report of a study of Wichita Falls, Texas,  
Pinnell-Anderson-Wilshire and Associates, Inc.,  
March 1972.

PURPOSE: To demonstrate the application of systems manage-  
ment techniques to problems of the fire service by  
experimental application of the techniques in  
Wichita Falls, Texas.

SUMMARY: The demonstration application of various systems  
analysis techniques in Wichita Falls, Texas is  
discussed. Interim reports on eleven different  
analytic efforts are grouped into the following  
three phases:

- Operational Analysis and Computer Utilization.  
A detailed analysis of the existing opera-  
tions of the Wichita Falls Fire Department  
is presented, and designs are presented for  
a computer-based management information  
system to make improved use of operational  
data.
- Simulation Model Development. A simulation  
model is developed to test different location  
and response policies for the Wichita Falls  
Fire Department. Detailed discussion of  
the data used in the model is included.
- Systems Analysis of Fire Protection Operations.  
The data developed in the first phase, the  
simulation model developed in the second, and  
a number of other techniques are used to make

preliminary studies of possible improvements in the Wichita Falls Fire Department.

**ABSTRACT:**

The results of a demonstration study of the Wichita Falls Fire Department are presented in three volumes. The work of eleven interim analyses on specific issues is grouped into three broad phases.

The first phase of the study concerns the analysis of the management information available to fire officials. The fire reporting system employed in Wichita Falls was extensively analyzed and a revised system developed. A computerized fire inspection system is also developed. This system assures that various buildings are inspected on a timely and repetitive basis.

The second phase of the study developed a computer simulation of the operations of the Wichita Falls fire suppression forces (See Anderson [A-2] for additional discussion of this simulation). The model generates alarms in a pattern like that experienced in Wichita Falls, moves units to and from the fire scene, and tabulates results in terms of both mean response ~~time~~ and mean fire loss. Details are provided on the fitting of the input distributions to existing experience in Wichita Falls.

The third phase of the study draws on the tools developed in the first two phases to analyze some policy questions. Alarm data from the five year period which had been computerized was reviewed for variations by geographic location and time, as well as for mix of alarms. This analysis suggested a number of reallocations of resources to make more manpower available at times of greatest demand.

A second analysis developed a subjective, scoring model approach to evaluating the hazards and the state of fire protection in various parts of the city of Wichita Falls. Test implementation of the procedure appeared to validate it as a useful tool for identifying problems in the mix of fire protection service provided different parts of the city.

Four demonstration applications of the simulation were also included in the third phase. Each addresses a different question of fire suppression forces allocation in Wichita Falls.

A final segment of this phase of the study addressed the "key rate" system used for setting insurance rates in Texas. The authors concluded that full compliance with the requirements of that system would lead to a fire service which was over-designed for the actual demand experienced.

THREATS TO  
INTERNAL  
VALIDITY:

The authors recognize that the purpose of their study was to demonstrate the value of system analysis techniques in fire protection. Thus, while the study could be criticized for its superficial analysis in some parts and uncritical application of more complex than necessary techniques in other parts, such criticism is probably not appropriate.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 2.1, 4.1, 5.1.3, 5.2.1, 5.2.2.1, 5.3.3,  
6.4, 7.1, 7.2

travel time,  $d_j$ , was originally determined for each FDZ from the opinion of fire service officials inspecting the areas, but has been reduced to the following regression equation of land use

$$d_j = 4.42 - .0518 \left( \begin{array}{c} \text{Permanent} \\ \text{population} \\ \text{per acre} \end{array} \right) - 2.69 \left( \begin{array}{c} \text{Density of} \\ \text{commercial} \\ \text{and industrial} \\ \text{land use} \end{array} \right) \\ - 5.59 \left( \begin{array}{c} \text{Density of} \\ \text{institutional} \\ \text{land use} \end{array} \right) - 1.47 \left( \begin{array}{c} \text{Density} \\ \text{of park} \\ \text{land use} \end{array} \right)$$

In terms of these two quantities and the frequency of incidents in FDZ  $i$ ,  $f_i$ , exposure is calculated

$$e_{ij} = f_i \max \{0, (t_{ij} - d_j)/d_j\} .$$

THREATS TO  
INTERNAL  
VALIDITY:

Not enough technical details are provided to assess the validity of the mathematical and statistical procedures outlined.

TEXT COM-  
MENTS ON  
EXTERNAL  
VALIDITY  
AND POLICY  
UTILITY:

Sections 5.1.3, 6.1.2

## APPENDIX C

### RESULTS OF POLICY UTILITY QUESTIONS PUT TO FIRE SERVICE PROFESSIONALS

As outlined in Chapter 1, an important part of the study leading to this report was the solicitation of the opinions of fire service professionals on the policy utility of various aspects of fire service management research. These professionals were not asked to evaluate individual research reports, but their opinions on broader questions and assumptions were sought and recorded. Numerous references to those opinions are included in the main body of the report.

This Appendix contains the details of the responses from these fire service professionals. A first section presents the results of the Professionals Panel seminar held on the Georgia Tech campus in June, 1974. A second section reports the more general responses of professionals attending the NFPA Seminar and Workshop in Fire Department Management Problem Techniques Using UFIRS Data which was held in Berkeley, California in July, 1974.

#### C.1 PROFESSIONALS PANEL

On June 24-26, 1974 a selected Professionals Panel of fire chiefs and experts in fire protection services met on the Georgia Tech campus for the purpose of assisting in the evaluation of external validity and policy utility of the fire service management research assembled for this report. The individuals who were invited to participate on this Panel were selected on the basis of knowledge and experience in the field of fire protection (as evidenced by progressive activities in the fire departments which they headed) or on the basis of their contributions to knowledge in the field of fire protection service management. The Professionals Panel members were as follows:

- Mr. Philip Chovan  
Georgia Fire Academy  
Georgia Institute of Technology  
Atlanta, Georgia 30332
- Mr. Hank Christen, President  
Local 134 - Atlanta  
3407 D Cumberland Drive  
Chamblee, Georgia 30341
- Mr. J. B. Gossett, Chief  
Fire Prevention Bureau  
Atlanta Fire Department  
46 Courtland St., S.E.  
Atlanta, Georgia 30303
- Mr. John E. Lee, Chief  
Charlotte Fire Department  
125 S. Davidson Street  
Charlotte, N. C. 28202
- Dr. Ralph Long  
Division of Advanced Technology Applications  
National Science Foundation  
Washington, D.C. 20550
- Dr. David Miller  
Assistant Professor  
Department of Industrial Engineering and Operations Research  
Virginia Polytechnic Institute  
Blacksburg, Virginia 24061
- Mr. P. C. O'Connor, Chief  
Technical Services Division  
Metropolitan Dade County Fire Department  
6000 S. W. 87th Avenue  
Miami, Florida 33143
- Mr. Joseph Swartz  
Research Division  
National Fire Protection Association  
470 Atlantic Avenue  
Boston, Massachusetts 02210
- Mr. P. O. Williams, Chief  
Atlanta Fire Department  
46 Courtland St., S.E.  
Atlanta, Georgia 30303

### C.1.1.1 OPERATION OF THE MEETINGS

Meetings of the Professionals Panel were conducted as seminars, with one session devoted to each of the major policy-related subjects discussed in the main chapters of this report. Each session was introduced by a brief description of the subject area presented by a member of the study team. This overview defined the subject area, reviewed the status of research in the area, outlined the important non-technical assumptions on which that research depended, and listed the important research results which had been obtained. Active discussion and questions were solicited from the Panel during and after each presentation.

The information sought from the Professionals Panel was their opinion on the policy utility of the problems addressed by fire researchers (i.e., would even a good solution to the problems be of any value in practical fire service management), the validity of important non-technical assumptions about the fire protection environment which were made by the researchers, and the degree of generality of specific research findings. After general discussion of these matters in each Panel session, the professionals were asked to give specific, scaled responses to a list of questions prepared by the study team.

Examples of the forms used to collect these specific responses are presented in the three figures which follow. The "Problem Grading Scale" (Figure C-1) solicited opinion on the policy utility of the research questions addressed by various authors. The professionals were asked to describe "how useful a good solution to the problem would be in practical fire protection work." The "Assumption Grading Scale" (Figure C-2) addressed the validity of non-technical assumptions in the research. The professionals were asked to indicate "how consistent the assumption is with your understanding of the true problem environment." Finally, the "Result Grading Schedule" (Figure C-3) dealt with the generality of valid research results obtained in particular settings. The professionals were asked to indicate "in how wide a range of fire protection agencies you believe the result would be valid."

Results of these specific responses from the Professionals Panel were tabulated by the study team on a one to five scale. Thus, for

PROBLEM GRADING SCALE  
(NSF FIRE POLICY RESEARCH STUDY)

Page \_\_\_\_\_

Responder \_\_\_\_\_

For each research problem discussed, indicate how useful a good solution to the problem would be in practical fire protection work.

1.	very useful	valuable	some value	little value	useless
2.	very useful	valuable	some value	little value	useless
3.	very useful	valuable	some value	little value	useless
4.	very useful	valuable	some value	little value	useless
5.	very useful	valuable	some value	little value	useless
6.	very useful	valuable	some value	little value	useless
7.	very useful	valuable	some value	little value	useless
8.	very useful	valuable	some value	little value	useless
9.	very useful	valuable	some value	little value	useless
10.	very useful	valuable	some value	little value	useless
11.	very useful	valuable	some value	little value	useless
12.	very useful	valuable	some value	little value	useless
13.	very useful	valuable	some value	little value	useless

FIGURE C-1. PROBLEM GRADING SCALE USED IN PROFESSIONALS PANEL SESSIONS



ASSUMPTION GRADING SCALE  
(NSF FIRE POLICY RESEARCH STUDY)

Page \_\_\_\_\_  
Responder \_\_\_\_\_

For each assumption presented, indicate how consistent the assumption is with your understanding of the true problem environment.

1.	very consistent	fairly consistent	debatable	fairly inconsistent	very inconsistent
2.	very consistent	fairly consistent	debatable	fairly inconsistent	very inconsistent
3.	very consistent	fairly consistent	debatable	fairly inconsistent	very inconsistent
4.	very consistent	fairly consistent	debatable	fairly inconsistent	very inconsistent
5.	very consistent	fairly consistent	debatable	fairly inconsistent	very inconsistent
6.	very consistent	fairly consistent	debatable	fairly inconsistent	very inconsistent
7.	very consistent	fairly consistent	debatable	fairly inconsistent	very inconsistent
8.	very consistent	fairly consistent	debatable	fairly inconsistent	very inconsistent
9.	very consistent	fairly consistent	debatable	fairly inconsistent	very inconsistent
10.	very consistent	fairly consistent	debatable	fairly inconsistent	very inconsistent
11.	very consistent	fairly consistent	debatable	fairly inconsistent	very inconsistent
12.	very consistent	fairly consistent	debatable	fairly inconsistent	very inconsistent
13.	very consistent	fairly consistent	debatable	fairly inconsistent	very inconsistent

FIGURE C-2. ASSUMPTION GRADING SCALE USED IN PROFESSIONALS  
PANEL SESSIONS

RESULT GRADING SCHEDULE  
(NSF FIRE POLICY RESEARCH STUDY)

Page \_\_\_\_\_

Responder \_\_\_\_\_

For each research result presented, indicate in how wide a range of fire protection agencies you believe the result would be valid. Note that (for this response) we are interested only in whether the result would be valid or correct, not necessarily whether it would be useful.

1.	almost nowhere	only selected cities	substantial no. of cities	most cities	almost everywhere
2.	almost nowhere	only selected cities	substantial no. of cities	most cities	almost everywhere
3.	almost nowhere	only selected cities	substantial no. of cities	most cities	almost everywhere
4.	almost nowhere	only selected cities	substantial no. of cities	most cities	almost everywhere
5.	almost nowhere	only selected cities	substantial no. of cities	most cities	almost everywhere
6.	almost nowhere	only selected cities	substantial no. of cities	most cities	almost everywhere
7.	almost nowhere	only selected cities	substantial no. of cities	most cities	almost everywhere
8.	almost nowhere	only selected cities	substantial no. of cities	most cities	almost everywhere
9.	almost nowhere	only selected cities	substantial no. of cities	most cities	almost everywhere
10.	almost nowhere	only selected cities	substantial no. of cities	most cities	almost everywhere
11.	almost nowhere	only selected cities	substantial no. of cities	most cities	almost everywhere
12.	almost nowhere	only selected cities	substantial no. of cities	most cities	almost everywhere
13.	almost nowhere	only selected cities	substantial no. of cities	most cities	almost everywhere

FIGURE C-3. RESULT GRADING SCHEDULE USED IN PROFESSIONALS  
PANEL SESSIONS

example, a response of "very useful" in the Problem Grading Scale was scored as a one, a response of "debatable" on the Assumption Grading Scale was scored as a three, and a response of "almost everywhere" on the Result Grading Schedule was scored as a five.

The remainder of this section presents the specific issues put to the Professionals Panel and the results of this numerical tabulation. The average response and the range of responses is provided for each issue. Subsection numbers correspond to chapter numbers in the body of this report.

C.1.2 MANAGEMENT AND URBAN POLICY ISSUES IN  
FIRE PROTECTION

	<u>Average</u>	<u>Range</u>
<u>Policy Utility of the Research Problems</u> (1 = very useful, 5 = useless)		
• How can the value of fire department services to the public be measured?	1.0	1.0-1.0
• How can fire protection service costs be allocated to business firms and households according to benefits received?	2.4	2.0-3.0
• What is the "optimal" quantity of fire department services? (i.e., that quantity of fire department services where marginal benefits equal marginal costs).	1.5	1.0-2.0
• What is the comparison of quality-quantity levels of fire protection supplied by a competitive producer vs. a bureaucratic monopoly?	2.5	1.0-3.0
• Are there economies of scale in fire protection services?	1.7	1.0-2.0

Validity of the Research Assumptions  
(1 = very consistent with environment, 5 = very inconsistent)

• Measures of fire protection output should not involve interactions with the consumers of that output (e.g., damage aversion is not a good measure).	2.7	2.0-4.0
---	-----	---------

	<u>Average</u>	<u>Range</u>
● Allocation of fire protection costs to businesses and households should be on the basis of benefits received.	2.6	1.0-5.0

Generality of the Research Results  
(applicable 1 = almost nowhere, 5 = almost everywhere)

● Since it is primarily the maintenance of a service capability rather than its exercise which imposes fire protection costs, a measure capturing that capability would also be well suited to the analysis of fire production costs. The quality of service measure will be termed "suppression capability" and will be measured by the total value remaining after fire department response to fires in a structure (type and size) selected as standard.	3.0	1.0-4.0
● The distribution of the total fire insurance premium reduction resulting from public fire protection services can serve as an allocation for distribution of costs.	3.3	2.0-5.0
● The variables of fire insurance rate and value of real property and tangible personal property can be used to allocate fire protection costs.	3.0	2.0-5.0

$$\text{Ratio} = \frac{\sum_{i=1}^n \frac{(\text{fire insurance rate})(\text{value of property of firm } i)}{(\text{value of property firm or household } i)}}{n}$$

● A suitable measure of fire protection service output is obtained by using a reversal of the fire insurance classification number. (Larger numbers are then representative of larger quantities of fire department output.)	3.1	1.0-5.0
--	-----	---------

	<u>Average</u>	<u>Range</u>
● There are significant economies of scale associated with municipal fire protection services (for standard levels of service for central cities from 50,000-1,000,000 population.	2.8	2.0-4.0
● Benefits can be estimated by determining the reduction in fire insurance cost per protection unit if the community increases the measured fire department output by one unit (fire rating).	3.1	2.0-4.0

C.1.3 ADMINISTRATION OF THE FIRE PROTECTION SERVICE

Policy Utility of the Research Problems  
(1 = very useful, 5 = useless)

● What is the social prestige-status of fire work in American society?	2.3	1.0-4.0
● What is the relative position of municipal fire departments in the political systems of their respective communities?	2.4	1.0-4.0
● What are the processes, mechanisms, and constraints within the framework of which municipal fire departments proceed to find potential fireman, screen the available candidates and decide to hire some and not to hire others?	1.4	1.0-2.0
● What motivates a man to become a fireman? What is his appraisal of fire service as a career? What were his knowledge and commitment to fire service prior to obtaining membership to the fire department?	2.1	1.0-4.0
● How do firemen view their profession?	1.7	1.0-3.0
● What is the effect of work schedules on family roles and participation in voluntary organizations?	2.4	1.0-3.0

	<u>Average</u>	<u>Range</u>
● What are some predictors of vocational success which could assist in the selection of personnel?	1.4	1.0-2.0
● What is an "optimum" manner for sequencing the purchase and retirement of fire engines? (Optimum means least discounted total costs)	2.5	1.0-3.0
● What measures of effectiveness are most useful in management of fire department activities?	1.0	1.0-1.0
● What is the relative effectiveness of various company manning patterns (3-man company, 4-man company, 5-man company, etc.) for fire suppression?	1.1	1.0-2.0
● How can special "major fire" suppression units be employed to reduce manning requirements in ordinary companies?	2.0	1.0-3.0
● How can fire suppression shifts be "best" scheduled so that workload requirements are met and hours per week conform to the agreed averages?	1.7	1.0-3.0

#### Validity of the Research Assumptions

(1 = very consistent with environment, 5 = very inconsistent)

● The maintenance costs of an engine increase linearly with age.	2.6	2.0-5.0
● The oldest engine is the proper one to retire when a retirement decision is made.	2.8	2.0-5.0
● A good measure of effectiveness of a company manning scheme is the time required to complete initial suppression and rescue operations and begin fire control.	1.8	1.0-3.0
● Company manning schemes should be evaluated primarily on the quality of response to structure fires.	2.3	1.0-3.0
● The number of days worked without a day off is an important criterion in evaluating manpower schedules.	1.8	1.0-3.0

	<u>Average</u>	<u>Range</u>
● The number of days off between work periods is an important criterion in evaluating manpower schedules.	2.0	1.0-3.0
● The sensitivity of a schedule to absenteeism is an important criterion in evaluation manpower schedules.	2.4	2.0-3.0
● Similarity of schedules for each company is an important criterion in evaluation manpower schedules.	2.3	1.0-3.0

Generality of the Research Results  
(applicable 1 = almost nowhere, 5 = almost everywhere)

● The public, in general, does not hold the fireman's occupation in high esteem.	2.6	1.0-4.0
● The sporadic nature of the public need for fire fighting seems to generate public indifference towards fire service.	3.3	2.0-4.0
● Firemen tend to assume an extremely defensive posture toward probing efforts into their own work roles.	4.4	4.0-5.0
● Firemen tend to assign high importance to their occupation.	4.1	2.0-5.0
● Firemen view their work schedules as generators of a great many difficulties which constrain the performance of their family and social roles.	3.3	1.0-5.0
● Factors which correlate with high vocational success (as determined by a rank ordering by the Fire Training Officer) are:	3.0	1.0-5.0
(a) Early family responsibility		
(b) Parental family adjustment		
(c) Total score on factors		
(d) School achievement		
(e) Higher educational achievement		
(f) Drive		

	<u>Average</u>	<u>Range</u>
(g) Leadership and group participation		
(h) Financial responsibility		
(i) Early family responsibility		
(j) Parental family adjustment		
(k) Stability		
● Based upon analysis of a Canadian experience, compulsory arbitration, while not infeasible, should be used as something of a last resort. The fear of compulsory arbitration as a destroyer of collective bargaining was not substantiated by the Canadian case.	3.7	2.0-5.0
● Three-man companies can operate pre-connected lines, but 4-man companies are needed for full ground level structures, and 5-man companies are necessary for multi-story operations.	2.6	1.0-5.0

#### C.1.4 FIRE INFORMATION AND COMMUNICATIONS SYSTEMS

<u>Policy Utility of the Research Problems</u> (1 = very useful, 5 = useless)		
● What are the objectives of a computer based management information and control system for fire protection service?	1.0	1.0-1.0
● What information and reports should the system provide?	1.4	1.0-2.0
● What information should be input to the system and how should it be captured and entered?	1.4	1.0-2.0
● What are the justifications for a computer based management information and control system?	1.4	1.0-2.0
● Should the system be justified on an economic basis only?	2.4	1.0-3.0
● Can malicious false alarms be reduced by replacing telegraph type systems with telephone type systems?	2.2	1.0-3.0



	<u>Average</u>	<u>Range</u>
● How do dispatching delays vary with alarm rate and how do such delays compare with turn-out time and travel time?	1.7	1.0-2.0

Validity of the Research Assumptions  
(1 = very consistent with environment, 5 = very inconsistent)

● The MICS should reflect a synthesis of the state-of-the-art in information technology and specific operationally based information requirements identified by an analysis of the present system.	1.6	1.0-5.0
● The MICS design should be based on objectives which the system is expected to meet and the functions which are identified as being necessary to the attainment of these objectives.	1.4	1.0-2.0
● There are benefits to be gained from a <u>uniform</u> reporting system--(i.e., a system which is compatible with similar systems at local, state, and national levels).	1.0	1.0-1.0

C.1.5 CRITERIA FOR SUPPRESSION RESOURCE ALLOCATION

Policy Utility of the Research Problems  
(1 = very useful, 5 = useless)

● What criteria should be used in allocating fire suppression resources to various areas and fires?	1.1	1.0-2.0
● How do fire losses and injuries increase with burning time?	1.6	1.0-3.0
● How do the resources needed to suppress a fire increase as burning time increases?	1.8	1.0-3.0
● What is the relationship between response time and response distance?	2.0	1.0-4.0
● How should individual response times be combined into an overall criterion for resource allocation?	2.0	1.0-4.0

	<u>Average</u>	<u>Range</u>
● How can the seriousness of fires in a given area be estimated?	1.5	1.0-2.0
● Develop models for predicting fire incidence (i.e., demands for fire suppression services).	1.0	1.0-1.0
● Develop a prediction equation for predicting the number of fires in a specified tract over some specific time period.	1.4	1.0-2.0
● A method for short-term (10-20 min.) prediction of the incidence rate for various types of fire alarms as a function of location, time, method of reporting, and weather conditions.	1.9	1.0-4.0
● Estimate quantitatively the risk of fire in an enclosed shopping center.	2.1	1.0-3.0
● A method for predicting the next days probable fire load.	2.3	1.0-4.0
● Develop a model which predicts the probability that a given box-reported alarm signifies a serious fire.	1.4	1.0-2.0
● Develop a model to predict the "serious alarm" rate in a given small area.	1.5	1.0-2.0
● Can malicious false alarms be reduced by replacing telegraph-type alarm systems with telephone-type systems?	1.1	1.0-2.0

Validity of Research Assumptions

(1 = very consistent with environment, 5 = very inconsistent)

● Property loss and injuries increase as time from the ignition of a fire increases.	1.3	1.0-2.0
● Response time is a significant part of the total time from ignition of a fire until the first suppression units arrive at the scene.	1.6	1.0-3.0
● After some amount of burning time the loss associated with a fire increases very little.	2.5	2.0-3.0

	<u>Average</u>	<u>Range</u>
● The longer a fire burns before suppression forces arrive, the more suppression resources are required to control it.	1.8	1.0-3.0
● Weighted averages of response times are good aggregate measures of the response performance of suppression resource allocations.	2.1	1.0-3.0
● In calculating overall measures of response performance, response times to fire calls should be adjusted for fire seriousness as well as for number of fires.	1.5	1.0-2.0
● The relative response performance in different neighborhoods is an important criterion for fire suppression allocation.	2.1	1.0-3.0
● Regardless of the averages, suppression allocation schemes should not be considered which exceed certain upper bounds or limits on response time to given areas.	2.3	1.0-4.0
● Response to fire calls is much more important than response to non-fire calls in allocating fire suppression resources.	2.8	1.0-5.0
● Adherence to fire insurance standards for response distances should be a major concern in allocating fire suppression resources.	3.3	3.0-4.0

#### Generality of Research Results

(applicable 1 = almost nowhere, 5 = almost everywhere)

● The maximum area of a fire increases with the burning time of a fire.	5.0	5.0-5.0
● The total quantity of water needed to control a fire increases with the burning time of the fire.	5.0	5.0-5.0
● The maximum application rate of water (in gallons per minute) needed to control a fire increases with the burning time of the fire.	5.0	5.0-5.0

	<u>Average</u>	<u>Range</u>
● The true distance traveled by a suppression unit to a fire averages higher than either straight line or rectilinear distance.	4.4	3.0-5.0
● Response time for fire suppression units increases more than in proportion to distance on short runs, but proportionally to distance for longer runs.	4.2	2.0-5.0
● The average response speed of fire suppression units is similar in daytime and nighttime hours.	3.3	1.0-5.0
● A prediction equation which relates independent variables such as Fire Hazard Index, Socio-Economic Index, Number of Commercial and Manufacturing Plants. (Can be used to predict the number of fires in a specific tract over some time period).	2.1	1.0-4.0
● Fire incidence in a city district is directly proportional to population density.	3.0	1.0-5.0
● False alarms follow a seasonal pattern.	3.6	2.0-4.0
● The number of non-structural fires increase with higher temperatures and decrease with higher relative humidity.	3.6	2.0-5.0
● Fires in abandoned buildings are disproportionately more frequent than in occupied buildings.	4.3	3.0-5.0
● Analysis of data on fires in enclosed shopping centers in England during 1967 indicate:	2.8	2.0-5.0
(a) fires may be expected about twice a year in a 200-shop mall.		
(b) such centers call for additional fire protection.		

	<u>Average</u>	<u>Range</u>
as locating one additional company given that present company locations are fixed.		
• Within primary response districts for fire suppression companies, fire calls tend to be fairly evenly spread over the land area of the district.	3.1	2.0-5.0
• A substantial majority of fire calls in an area are answered by the fire company with "home base" nearest the site of the fire.	1.5	1.0-2.0
• Current locations of fire stations and companies are fairly good in terms of minimizing response time to fire calls.	2.1	1.0-3.0
• Savings of 5-15 percent in average response time to fire calls are relatively insignificant.	2.8	2.0-3.0
• It is appropriate to design suppression districts on the basis of minimizing average response time from the <u>nearest</u> company location.	1.8	1.0-3.0
• Realistically, the alternative locations for a fire station in an area are usually limited to a fairly small number of possibilities.	1.8	1.0-3.0
• Most fire departments today dispatch units to alarms according to a predetermined response for each type of alarm.	1.5	1.0-3.0
• In a significant majority of cases, the "first choice" fire suppression units to dispatch to an alarm are all available.	1.8	1.0-2.0
• A good rule for determining how many units to dispatch to an alarm is balance the risk of the first alarm being inadequate, with the risk of the second alarm being inadequate, etc.	2.5	1.0-3.0
• Considering entire cities and mutual aid agreements, there are almost always some free units available to respond to incoming fire alarms.	1.5	1.0-2.0

	<u>Average</u>	<u>Range</u>
● The chance that an alarm is for a serious fire should be considered in determining how many units to dispatch.	1.4	1.0-2.0
● The number of units in the surrounding area which are busy at the time of an alarm should be considered in determining how many units to dispatch.	1.8	1.0-2.0
● The usual frequency of alarms coming from the area surrounding an alarm during the current month, day, and time of day, should be considered in determining how many units to dispatch.	2.1	1.0-3.0
● Most "call outs" are received by fire suppression companies at their station rather than while the company is in transit from another alarm.	1.1	1.0-2.0
● The decision that a relocation is necessary should be based on whether there are areas of the city with no available company within a given distance of the area--regardless of whether alarms in the area are likely.	1.5	1.0-3.0
● Once a relocation is necessary, vacant locations should be chosen for occupancy by a relocated company in such a way that minimum coverage is restored to all areas by the smallest number of company relocations.	2.3	1.0-3.0
● It rarely makes sense to move already relocated companies from one vacant station to another, i.e., companies to be relocated should be chosen from those available and in their permanent stations.	2.9	2.0-5.0
● When a relocation becomes necessary, the units chosen for relocation should be picked	1.7	1.0-3.0

to produce the minimum increase in overall average response time.

#### Generality of the Research Results

(applicable 1 = almost nowhere, 5 = almost everywhere)

	<u>Average</u>	<u>Range</u>
<ul style="list-style-type: none"> <li>● Locating fire stations and companies optimally within given districts is likely to produce no more than 5-15 percent reductions in average response time to fire calls.</li> </ul>	2.9	2.0-4.0
<ul style="list-style-type: none"> <li>● Significantly better average response time performance will be obtained by basing dispatch decisions on the actual situation at the time of an alarm rather than on pre-determined dispatch rules.</li> </ul>	3.6	2.0-5.0
<ul style="list-style-type: none"> <li>● When the proportion of companies in an area which are busy is relatively low, it is best to send the closest units to an alarm.</li> </ul>	4.5	4.0-5.0
<ul style="list-style-type: none"> <li>● When the proportion of companies in an area which are busy is relatively high, it is best to "cheat" and send slightly more distant units in order to be in a good position to respond to future alarms.</li> </ul>	2.6	1.0-5.0
<ul style="list-style-type: none"> <li>● If consideration is given to the ability to respond to future alarms in choosing units to dispatch to a current alarm, the balance in company workloads will be significantly improved.</li> </ul>	2.7	2.0-5.0
<ul style="list-style-type: none"> <li>● If relocations are performed, in such a way that the increase in overall response time in vacated areas is minimized, the balance in company workloads will be significantly improved.</li> </ul>	3.0	2.0-5.0

#### C.1.7 PREVENTION RESOURCE MANAGEMENT

	<u>Average</u>	<u>Range</u>
<u>Policy Utility of the Research Problem</u> (1 = very useful, 5 = useless)		
● What are the characteristics of juveniles who start fires? When and where are the fires started?	1.9	1.0-3.0
● With what frequency should structures of a specified class be routinely inspected in order to minimize the expected potential seriousness of fires?	1.6	1.0-3.0
● How should inspection districts be designed in order to equalize inspector work loads?	1.7	1.0-3.0
● How can a computer-assisted inspection scheduling and work assignments be made so as to balance week to week work loads of an inspector?	1.6	1.0-3.0
● What is the relationship between inspection frequency and fire incidence in buildings of various occupancy types?	1.7	1.0-3.0
● Can the causes of fire be meaningfully related to fire inspection practices?	1.7	1.0-2.0

<u>Validity of the Research Assumptions</u> (1 = very consistent with environment, 5 = very inconsistent)		
● Potential seriousness of fires, (i.e., potential economic loss and potential for human injury and death) subjectively determined, is a satisfactory criteria for decision making relative to fire inspection management.	1.4	1.0-2.0
● Potential seriousness can be subjectively estimated and quantified.	2.1	1.0-5.0
● Time required to perform inspections is independent of the rate of inspections.	2.4	1.0-4.0
● Fire inspections are conducted by full-time inspectors.	1.7	1.0-3.0



	<u>Average</u>	<u>Range</u>
● Factors which account for the major uncontrollable influences on inspection effectiveness are (a) occupancy types, and (b) area in which the building is located.	2.3	1.0-3.0

Generality of the Research Results  
(applicable 1 = almost nowhere, 5 = almost everywhere)

● A model was constructed for determining inspection frequencies and inspection districts which result in minimum expected potential seriousness of fires.	2.9	2.0-4.0
● A method is developed for estimating the probability,	3.1	2.0-5.0

$$P_{iklt}(z)$$

of a building of type k occupancy in area i having  $\ell$  fires during the  $t^{\text{th}}$  six-month interval ( $t = 1$  implies April-September,  $t = 2$  implies October-March), when the frequency of scheduled, routine inspections is  $z$  per year.

## C.2 NFPA SEMINAR AND WORKSHOP GROUP

As an outgrowth of his participation in the meeting of the Professionals Panel on the Georgia Tech campus, Mr. Joseph Swartz of the National Fire Protection Association (NFPA) designed and administered a survey putting similar policy utility issues to a larger group of fire service professionals. A list of research problems associated with each of the policy-related areas discussed at the Georgia Tech meeting was prepared, and professionals were asked to rank the importance of the various groups of questions. For each group, they were also asked to answer "yes" or "no" to the following questions?

- Validity: "Do you believe, in general, these are valid problems?"

- Completeness: "Does this seem to be a relatively complete list of the problems?"
- Significance: "Would answers to these problems help your department significantly reduce fire casualties, losses, or other costs?"

Swartz's questionnaire was administered to the participants in an NFPA Seminar and Workshop on Fire Department Management Problem Techniques Using UFIRS Data which was held in Berkeley, California in July, 1974. Mr. Swartz was kind enough to supply the study team with his results. The responses of the twenty-two fire service professionals who responded are summarized in Table C-1. A copy of the questionnaire makes up the remainder of this Appendix.

TABLE C-1

## RESULTS OF SURVEY AT NFPA SEMINAR AND WORKSHOP

Problem Rank	Validity			Completeness			Significance		
	Yes	No	NA	Yes	No	NA	Yes	No	NA
1. Prevention Resource Management	22	0	0	15	7	0	19	3	0
2. Criteria for Fire Suppression Allocation	20	1	1	11	10	1	18	3	1
3. Suppression Manpower Allocation	20	0	2	13	7	2	20	0	2
4. Administrative Management of the Fire Services	19	2	1	11	10	1	16	5	1
5. Suppression Equipment/Facilities Allocation	21	0	1	15	5	2	17	1	4
6. Urban Policy Issues in Fire Protection	21	0	1	13	8	1	15	3	4
7. Fire Information and Communication Systems	21	0	1	16	5	1	17	4	1
8. Demand for Fire Suppression Services	18	1	3	11	8	3	16	2	4
Cumulative									
Number	162	4	10	105	60	11	138	21	17
Percent	92.0	2.3	5.7	59.6	34.1	6.3	78.4	11.9	9.7

UFIRS Seminar and Workshop Questionnaire

Berkeley, California

July 14, 1974

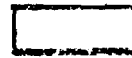
The attached questionnaire is intended to get your impressions and opinions prior to our discussions. At the conclusion of the discussions you may wish to alter your rankings, add explanations and comments. However, we wish your opinions unbiased by what you hear, since you are the ones who really understand the problems. You live and work with them. What you will hear during these sessions is a report on what has or can be done and not what should be done. Your thoughts during or after hearing the presentations will be recorded, studied, and reported to you.

Please do the following right now:

1. Provide identifying information

City \_\_\_\_\_ Title \_\_\_\_\_ Name \_\_\_\_\_  
(if you desire)

2. Read each topical area and shuffle them so that the most important is on top, the next most important second, etc. (Important being defined as the most interest to you right now as you see it and not as you believe it should be.)
3. Number the problem areas from 1 to 8 in the block called ranking.
4. Answer the questions on each page quickly. Please do not take over 15 minutes to complete the whole questionnaire. Strike a line through any problem you believe to be incorrect or unimportant.
5. Put this cover sheet over the questions. We will staple and collect them.
6. You will be given a blank questionnaire for your careful reflection. Comment during the remainder of the session and written comment to me at NFPA if you so desire.
7. We thank you.



URBAN POLICY ISSUES IN FIRE PROTECTION

1. How can the value of fire department services to the public be measured?
2. How can fire protection service costs be allocated to business firms and households according to benefits received?
3. What is the "optimal" quantity of fire department services?  
(i.e., That quantity of fire department services where marginal benefits equal marginal costs.)
4. What is the comparison of quality-quantity levels of fire protection supplied by a competitive producer vs. a bureaucratic monopoly.
5. Are there economies of scale in fire protection services?
6. What is an appropriate cost function for expressing the costs of fire protection service as a function of service level.
7. How should the costs of water supplied to the fire protection service be calculated?
8. Does the present grading system inhibit innovation and progress of fire protection.
9. What are the fire protection considerations in urban planning?

QUESTIONS

- |  | <u>Yes</u> | <u>No</u> |
|--|------------|-----------|
| 1. Do you believe, in general, these are valid problems?   | _____      | _____     |
| 2. Does this seem to be a relatively complete list of the problems?  | _____      | _____     |
| 3. Would answers to these problems help your department significantly reduce fire casualties, losses, or <u>other</u> costs? | _____      | _____     |

# ADMINISTRATIVE MANAGEMENT OF THE FIRE SERVICE

1. What is the relationship between size, number of levels in the hierarchy of organizational structure, departmentalization, and the proportion of personnel formally engaged in administrative activities and the extent to which organizational goals are met?
2. What are the interrelationships between organizational structure and functioning, group composition and interaction, and individual behavior?
3. What is the social prestige-status of fire work in American society?
4. What is the relative position of municipal fire departments in the political systems of their respective communities?
5. What are the processes, mechanisms, and constraints within the framework of which municipal fire departments proceed to find potential fireman, screen the available candidates and decide to hire some and not to hire others?
6. What motivates a man to become a fireman? What is his appraisal of fire service as a career? What were his knowledge and commitment to fire service prior to obtaining membership to the fire department?
7. How do firemen view their profession?
8. What is the effect of work schedules on family roles and participation in voluntary organizations?
9. What are some predictors of vocational success which could assist in the selection of personnel?
10. What is an "optimum" manner for sequencing the purchase and retirement of fire engines, other apparatus and equipment?
11. What measures of effectiveness are most useful in management of fire department activities?

## QUESTIONS

- |  | <u>Yes</u> | <u>No</u> |
|--|------------|-----------|
| 1. Do you believe, in general, these are valid problems?   | _____      | _____     |
| 2. Does this seem to be a relatively complete list of the problems?  | _____      | _____     |
| 3. Would answers to these problems help your department significantly reduce fire casualties, losses, or <u>other</u> costs? | _____      | _____     |

SUPPRESSION MANPOWER ALLOCATION

1. What is the relative effectiveness of various company manning patterns (3 man company, 4 man company, 5 man company, etc.) for reducing fire losses?
2. What is the relative effectiveness of various company manning patterns for reducing civilian casualties?
3. What is the relative effectiveness of various company manning patterns for reducing firefighter casualties?
4. How can special "major fire" suppression units be employed to reduce manning requirements in ordinary companies?
5. How can fire suppression shifts be "best" scheduled so that workload requirements are met and hours per week conform to the agreed average?
6. How can seasonal adjustments in vacation scheduling and company manning patterns be used to improve manpower usage?

QUESTIONS

- |  | <u>Yes</u> | <u>No</u> |
|--|------------|-----------|
| 1. Do you believe, in general, these are valid problems?   | _____      | _____     |
| 2. Does this seem to be a relatively complete list of the problems?  | _____      | _____     |
| 3. Would answers to these problems help your department significantly reduce fire casualties, losses, or <u>other</u> costs? | _____      | _____     |

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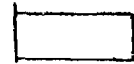
# FIRE INFORMATION AND COMMUNICATIONS SYSTEMS

1. What are the objectives of a computer based management information and control system for fire protection service?
2. What information and reports should the system provide?
3. What information should be input to the system and how should it be captured and entered?
4. What are the justifications for a computer based management information system?
5. Should the system be justified on an economic basis only?
6. Can malicious false alarms be reduced by replacing telegraph type systems with telephone type systems?
7. How do dispatching delays vary with alarm rate and how do such delays compare with turn-out time and travel time?
8. When (under what conditions) is computer aided dispatch system justified?

## QUESTIONS

- |  | <u>Yes</u> | <u>No</u> |
|--|------------|-----------|
| 1. Do you believe, in general, these are valid problems?   | _____      | _____     |
| 2. Does this seem to be a relatively complete list of the problems?  | _____      | _____     |
| 3. Would answers to these problems help your department significantly reduce fire casualties, losses, or <u>other</u> costs? | _____      | _____     |





CRITERIA FOR FIRE SUPPRESSION ALLOCATION

1. What criteria should be used in allocating fire suppression resources to various areas and fires?
2. How do fire losses and injuries increase with burning time?
3. How do the resources needed to suppress a fire increase as burning time increases?
4. What is the relationship between response time and response distance?
5. How should individual response times be combined into an overall criterion for resource allocation?
6. How can the seriousness of fires in a given area be estimated?

QUESTIONS

- |  | <u>Yes</u> | <u>No</u> |
|--|------------|-----------|
| 1. Do you believe, in general, these are valid problems?   | _____      | _____     |
| 2. Does this seem to be a relatively complete list of the problems?  | _____      | _____     |
| 3. Would answers to these problems help your department significantly reduce fire casualties, losses, or <u>other</u> costs? | _____      | _____     |

--

### DEMAND FOR FIRE SUPPRESSION SERVICES

1. What models are needed for predicting fire incidence (i.e. Demands for fire suppression services)?
2. What is the equation that will allow the prediction of the number of fires in a specified tract over some specification period?
3. What is the method for predicting the short term (10-20 minutes) incidence rate for various types of fire alarms as a function of location, time, method of reporting, and weather conditions.
4. What is the quantitative risk of fire in an enclosed shopping center or other occupancy type?
5. How can the next days probable fire load be predicted?
6. What is the probability that a given box reported alarm signifies a serious fire?
7. What is the predicted "serious alarm" rate in a given small area?
8. Can malicious false alarms be reduced by replacing telegraph-type alarm systems with telephone-type systems?

### QUESTIONS

- |  | <u>Yes</u> | <u>No</u> |
|--|------------|-----------|
| 1. Do you believe, in general, these are valid problems?   | _____      | _____     |
| 2. Does this seem to be a relatively complete list of the problems?  | _____      | _____     |
| 3. Would answers to these problems help your department significantly reduce fire casualties, losses, or <u>other</u> costs? | _____      | _____     |

SUPPRESSION EQUIPMENT/FACILITIES ALLOCATION

1. What suppression resources (stations and companies) should be allocated to various geographic areas and fire calls?
2. Where should fire stations be located?
3. Where should fire companies be assigned as "home base"?
4. Where should fire companies and stations be located within predetermined primary response districts?
5. How many fire companies are needed to serve a predetermined primary response district?
6. How should primary response districts for fire suppression units be designed?
7. How do given allocations of fire suppression stations and companies perform as the number of busy units increases?
8. How many of the available suppression companies should be dispatched to a given fire call?
9. Which of the available suppression companies should be dispatched to a given fire call?
10. When is it necessary to perform a relocation of fire suppression companies?
11. When a relocation is necessary, which company locations in the depleted area should be manned by relocated units?
12. When a relocation is necessary, which available units should be relocated into the unmanned stations?

QUESTIONS

- |  | <u>Yes</u> | <u>No</u> |
|--|------------|-----------|
| 1. Do you believe, in general, these are valid problems?   | _____      | _____     |
| 2. Does this seem to be a relatively complete list of the problems?  | _____      | _____     |
| 3. Would answers to these problems help your department significantly reduce fire casualties, losses, or <u>other</u> costs? | _____      | _____     |

PREVENTION RESOURCE MANAGEMENT

1. What are the characteristics of persons who start fires? When and where are the fires started?
2. With what frequency should structures of a specified class be routinely inspected in order to minimize the expected potential seriousness of fires?
3. How should inspection districts be designed in order to equalize inspector work loads?
4. How can a computer assisted inspection scheduling and work assignments be made so as to balance week to week work loads of an inspector?
5. What is the relationship between inspection frequency and fire incidence in buildings of various occupancy types?
6. Can the causes of fire be meaningfully related to fire inspection practices?

QUESTIONS

- |  | <u>Yes</u> | <u>No</u> |
|--|------------|-----------|
| 1. Do you believe, in general, these are valid problems?   | _____      | _____     |
| 2. Does this seem to be a relatively complete list of the problems?  | _____      | _____     |
| 3. Would answers to these problems help your department significantly reduce fire casualties, losses, or <u>other</u> costs? | _____      | _____     |

## APPENDIX D

### PUBLISHERS OF FIRE SERVICE MANAGEMENT RESEARCH

In the process of preparing this report, copies of approximately 350 papers and reports were obtained. The project team is indebted to the authors and publishers of these papers for furnishing copies. To make it even easier for readers to obtain copies of papers reviewed in this report, a list of publishers of fire research is contained in this Appendix.

One important source of fire literature is dissertations authored by Ph.D. students at various universities. Order numbers for dissertations can be obtained in the journal Dissertation Abstracts. Copies (in either microfilm or hard copy form) are available from

Xerox University Microfilms  
300 North Zeeb Road  
Ann Arbor, Michigan 48104.

The other principal source of fire literature is articles in published journals. The following are the names and addresses of each journal containing at least two articles referenced in this report:

- The American City Magazine  
Buttenheim Publishing Corporation  
Berkshire Common  
Pittsfield, Massachusetts 01201
- Fire  
Unisaf Publications Ltd.  
Unisaf House  
32-36 Dudley Road  
Tunbridge Wells  
Kent, England

- Fire Chief Magazine  
625 N. Michigan Avenue  
Chicago, Illinois 60611
- Fire Command  
National Fire Protection Association  
470 Atlantic Avenue  
Boston, Massachusetts 02210
- Fire Engineering  
666 Fifth Avenue  
New York, New York 10019
- Fire Journal  
National Fire Protection Association  
470 Atlantic Avenue  
Boston, Massachusetts 02210
- Fire Technology  
National Fire Protection Association  
470 Atlantic Avenue  
Boston, Massachusetts 02210
- Firemen  
National Fire Protection Association  
470 Atlantic Avenue  
Boston, Massachusetts 02210
- International Fire Fighter  
International Association of Fire Fighters  
810 Rhode Island Avenue, N. E.  
Washington, D. C.
- Management Science  
The Institute of Management Sciences  
146 Westminster Street  
Providence, Rhode Island 02903

- Minnesota Municipalities  
League of Minnesota Municipalities  
3300 University Avenue, S. E.  
Minneapolis, Minnesota 55414
- Municipal Public Services Journal  
178-202 Great Portland Street  
London W1N 6NH  
England
- NFPA Quarterly  
National Fire Protection Association  
470 Atlantic Avenue  
Boston, Massachusetts 02210
- Nation's Cities  
National League of Cities  
1620 Eye Street, N. W.  
Washington, D. C. 20006
- National Civic Review  
formerly: National Municipal Review  
National Municipal League  
Carl H. Pforzheimer Building  
47 East 68th Street  
New York, New York 10021
- Operational Research Quarterly  
Pergamon Press Ltd.  
Maxwell House,  
Fairview Park,  
Elmsford, New York 10523
- Operations Research  
Operations Research Society of America  
428 E. Preston Street  
Baltimore, Maryland 21202

## APPENDIX F

### LIST OF AGENCIES CONDUCTING FIRE SERVICE MANAGEMENT RESEARCH

Much of the literature discussed in this report was prepared by a relatively small group of agencies actively involved in fire research. The following is a list of the names and addresses of those agencies conducting research described in at least two papers referenced in this report:

- Factory Mutual Research  
1151 Boston-Providence Turnpike  
Norwood, Massachusetts 02062
- Fire Research Station  
Borehamwood, Herts.  
England
- Home Office  
Scientific Advisory Branch  
Horseferry House  
Dean Ryle Street  
London SW1P 2AW
- IIT Research Institute  
10 West 35 Street  
Chicago, Illinois 60616
- International Association of Fire Fighters  
1750 New York Avenue, N. W.  
Washington, D. C. 20006
- International City Management Association  
1140 Connecticut Avenue, N. W.  
Washington, D. C. 20036



- Joint Fire Research Organization  
Borehamwood, Herts.  
England
- U. S. Department of Commerce  
National Bureau of Standards  
Washington, D. C. 20234
- National Fire Protection Association  
470 Atlantic Avenue  
Boston, Massachusetts 02210
- The New York City-Rand Institute  
545 Madison Avenue  
New York, New York 10022
- Systems Development Corporation  
2500 Colorado Avenue  
Santa Monica, California
- Texas A & M University  
College of Engineering  
College Station, Texas 77843
- University of Maryland  
Fire Protection Program  
College Park, Maryland 20742

## APPENDIX G

### INDEX BY AUTHOR

This Appendix provides an author index to the report. Both bibliographical references and text discussions are listed for each author of the reports and papers collected for this project.

The information provided for each author is of two types. The first set of numbers lists all bibliographical entries for work of the author. These numbers contain dashes. Bibliographical entries for those numbers which begin with an "A" are contained in Appendix A, and all other entries are in the "Other Related Papers" sections at the ends of the chapters corresponding to the numbers preceding the dashes. (The abstracts and evaluations of Appendix B are also arranged by the A-numbers.)

The second part of each entry lists the section numbers of the report where the author's work is discussed. These section numbers contain one or more periods.

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